PROJECT 2849

REPORT

TO

THE ROYAL COMMISSION ON THE OCEAN RANGER MARINE DISASTER

ON

THE ADEQUACY OF AVAILABLE SEABED INFORMATION AS INPUT TO DESIGN CRITERIA AND OPERATING CONSTRAINTS FOR EASTERN CANADA OFFSHORE EXPLORATORY DRILLING

Jacques, Whitford and Associates Limited

January 31, 1984

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SUMMARY

This report presents the results of a study to assess the adequacy of available seabed information as input to design criteria and operating constraints for eastern Canada offshore exploratory drilling. The primary emphasis of the study is evaluation of the adequacy of the information in terms of the influence of seabed conditions on safety.

Both the type and distribution of seabed sediments and the occurrence of significant geologic features have to be considered in the assessment of seabed conditions. Available data on the types and distribution of eastern Canada offshore sediments is based primarily on geophysical surveys and geological interpretation; a condensation of these data is presented as a mapping of seabed sediments. Potentially significant geologic features and conditions have been identified in the eastern Canada offshore; these are discussed in the report but available data are not sufficient to permit their mapping.

Exploration drilling equipment which interacts with the seabed includes jack-up drilling rigs, anchors, and well conductors. The most critical interaction is that of jack-up units which depend completely upon the seabed for their support and which are susceptible to a variety of foundation problems. Analytical procedures are available for predicting the behavior of jack-up unit foundations and for designing well conductors; the design and performance of anchors are based on empirical methods and proof testing.

For input to design criteria and operating constraints, detailed information on the geotechnical properties of the seabed sediments is required. Available data determined from geophysical surveys does not provide the required geotechnical information and is not sufficient to permit evaluation of the effects of seabed conditions on the safety of offshore drilling operations. It is therefore concluded that the available seabed information is not adquate as input to design criteria and operating constraints for offshore exploratory drilling.

1. INTRODUCTION

This report presents the results of a study of available seabed information on the Eastern Canada offshore with regard to the design and performance of exploration drilling operations. The major emphasis of the study was to evaluate the adequacy of the information in terms of the potential effect of seabed conditions on personnel safety.

The study area is the eastern Canada offshore extending from the shoreline to the limits of jurisdictional claims. The area extends from the Canada-United States boundary to approximately 75° north latitude. (Figure 1.1)[1]

The study included several tasks. The first task was to undertake a review of available literature and on-going research and development activities to enable an evaluation of the extent to which other efforts are addressing the study topic. A second task was to provide a general description of the eastern Canada offshore seabed based on published data. A third task involved describing the interaction between offshore drilling equipment and the seabed and state-of-the-art methods available for analyzing this interaction. The final task was to evaluate the adequacy of the existing information for use in these analyses.

The organization of the report is as follows: First, a summary of published information on Eastern Canada offshore seabed sediment distribution is presented and the occurrence of significant shallow geologic features is noted. Appendix 1 presents brief descriptions of these geologic features. The following section describes exploration drilling equipment which interacts with the seabed, the nature of the interaction and the methods used for its analysis; case histories of significant seabed-related drilling accidents are referenced and pertinent research activities are noted. In the final section, the adequacy of the available information is evaluated with respect to the equipment-seabed interaction described and present practices.

The present study considered only shallow geologic features and sediment conditions that may influence the safety of exploration

[1] Figures at end of section

drilling operations; in qualitative terms, the depth is that required to provide stable mooring and foundation systems. The effect of deep geologic conditions such as over-pressured formations is outside the scope of this report.

Figure 1.1: Study Area and Physiographic Regions

2. EASTERN CANADA OFFSHORE SEABED CONDITIONS

The seabed conditions in the study area are described in this portion of the report. Two different but closely related aspects of the seabed conditions are presented, that is, the type and distribution of seabed sediments, and the geologic features and conditions that are of potential significance to the safety of eastern Canada offshore drilling operations. The second aspect, geologic features and conditions, might be better described as simply seabed features since features and conditions produced by environmental agents are included in this category. The term geologic features and conditions has been retained, however, in that this is the term which is commonly used. The distribution of the seabed sediments, derived from published data, is given in the form of seabed sediment maps. It was not possible to map the geologic features and conditions on a regional basis because of the lack of existing data.

2.1 Seabed Sediment[1] Mapping

2.1.1 Data Sources and Sediment Classification

In developing the classification of sediments on the continental shelf offshore eastern Canada, the available data by which the physical properties of the seabed sediments could be effectively mapped on a regional scale were reviewed. The extent and type of available data limited the classification to recognition of three characteristics of an area: (1) type of material in the seabed; (2) thickness of unconsolidated sediments; and (3) seafloor slope.

[1] The terms "sediment" and "soil" are used interchangeably in this report to describe unconsolidated materials above bedrock; the term "sediment" is commonly used in geological contexts, "soil" in engineering contexts.

The seabed sediment mapping shown on Figures 2.1 to 2.6 is based largely on information contained in a report by Jacques/McClelland Geosciences, inc. (JMGI, 1982) and reflects the knowledge at that time; updating of the information by various researchers, particularly those at the Atlantic Geoscience Centre, is an ongoing process. JMGI used published geologic maps, seismic facies or acoustic-morphologic maps, geologic cross-sections and geophysical records, information contained in various geologic reports and limited unpublished sample data. The lists below describe the sources. The sources are listed approximately according to the extent they were applied in the mapping. The lists are organized by major physiographic regions (Fig. 1.1):

Source	Type of Information
Scotian Shelf (Fig. 2.2 & 2.3)	
MacLean and King (1971)	Geologic Map and Report
King (1970)	Geologic Map and Report
Fader, King & MacLean (1977)	Geologic Map and Report
Drapeau and King (1972)	Geologic Map and Report
MacLean, Fader, & King (1977)	Geologic Map and Report
King and MacLean (1976)	Geologic Map and Report
King and Fader (1982)	Personal Communication to JMGI
King, MacLean, & Drapeau (1972)	Paper
King (1969)	Paper
Laurentian Channel (Fig. 2.2 & 2.3)	
Fader, King & Josenhans(in press)	Geologic Map and Report
Loring and Nota (1973)	Geologic Map and Report
MacLean and King (1971)	Paper
King and MacLean (1970b)	Paper
Gulf of St. Lawrence (Fig. 2.2)	
Loring and Nota (1973)	Geologic Map and Report
Krank (1971)	Paper
Shearer (1973)	Paper

Source	Type of Information
Grand Banks (Fig. 2.3 & 2.4)	
Fader, King & Josenhans(in press)	Geologic Map and Report
Fader and King (1981)	Paper
King and Fader (1981)	Map and Report
Fader and King (1982)	Personal communication to JMGI
Lewis and Barrie (1981)	Paper
King and Fader (1976)	Paper
King and MacLean (1976)	Paper
Grant (1971)	Thesis
Grant (1972)	Paper
Slatt (1977)	Paper
Slatt (1974)	Paper
Stehman (1976)	Paper
Gevork'yan & Kachanov (1976)	Paper
Northeast Newfoundland Shelf (Fig 2.4 & 2.5)	
Dale (1979)	Thesis
Dale and Haworth (1979)	Paper
Grant (1971)	Thesis
Grant (1972)	Paper
Haworth,Grant & Folinsbee (1976)	Paper
Haworth, Poole, Grant and Sandford (1976)	Paper
Piper,Mudie, Aksu & Hill (1978)	Paper
Slatt (1974)	Paper
Labrador Shelf (Fig. 2.5 & 2.6)	
Grant (1971)	Thesis
Grant (1972)	Paper
van de Linden, Fillon & Monahan (1976)	Geologic Map and Report
Fillon and Harmes (1982)	Paper
Vilks (1980)	Paper
McMillan (1973)	Paper

The report by JMGI (1982) covered a study area of the continental shelf of eastern Canada extending from the Gulf of Maine to the Labrador Shelf. For the purposes of the current study, therefore, it was necessary to attempt to extend the data to include the Baffin Island Shelf. Due to the limited amount of seabed survey work that has been carried out in this region, this was not possible. The Atlantic Geoscience Centre has performed some survey work in the area and the field data is currently being interpreted.

Available data suggests that all of the sediment types shown on Figures 2.2 to 2.6 and described in Section 2.1.2 also occur on the Baffin Island shelf. The following are sources of information on the geology of the Baffin Island shelf. References are given in the Bibliography.

Source	Type of Information
Lewis, MacLean and Falconer (1980)	Paper
MacLean (in prep.)	Paper
MacLean (1982)	Paper
MacLean and Srivastava (1981)	Paper
MacLean, Srivastava and Haworth (1982)	Paper
MacLean, Falconer and Levy (1981)	Paper
Osterman (1982)	Paper
Praeg (1982)	Relief Map

In general, data on the seabed conditions to be found on the eastern Canada offshore becomes more limited with increasing latitude. The relative reliability of the sediment type boundaries shown on Figures 2.2 to 2.6 is a function of the density of data coverage, as well as type of available data, quality of available data, and complexity of the geology within each area. Data on the continental slope is limited and scattered. The regional geology of the slope areas is as yet not well defined.

It is noted that the source data consists primarily of geophysical records, from which seabed sediment types have been inferred, with very limited sample information. Discussion of the significance of this is reserved for Section 4.

The seabed sediment maps should only be used in a relative sense to characterize regional conditions, since in many areas the original mapping of subsurface sediments was interpretive. There is recent evidence that some inaccuracies in the interpretation do exist. For example, the material indicated as near surface rock around Sable Island has been shown by borehole data to consist of deep deposits of dense sands and hard clays. Interpretation of the sediment conditions in this and other areas is being refined by researchers in the field as additional data becomes available.

2.1.2 Description of the Seabed Sediments

Based on the previously published mappings of the seabed sediments on the eastern Canada offshore and interpretations of available data, the seabed sediments have been categorized in five groupings: (1) rock; (2) glacial drift; (3) sand and gravel; (4) competent fine-grained sediments; and (5) weak sediments. The following paragraphs describe the distribution of these categories as shown on Figures 2.1 to 2.6, and present briefly what is believed to be the geological origins of the sediments. In addition, areas where steep slopes may occur are indicated.

Rock

Rock is shown where it occurs at the seafloor or is covered by less than 3 m of unconsolidated sediments. Areas with less than 3 m of unconsolidated sediments were included in the rock category because it was not practical with the available data to attempt to resolve very thin unconsolidated sediments. The types of rock include

igneous or metamorphic, sedimentary and semi-consolidated Tertiary and Cretaceous bedrock. It is indicated that the "rock" on the outer Grand Banks and slope consists of semi-consolidated Tertiary and Cretaceous sedimentary materials which do not possess the degree of compaction and consolidation normally associated with materials classified as rock; in a geotechnical engineering context, these "rocks" would be considered dense or hard soils.

Glacial Drift

Till is the predominant material within this category but significant amounts of stratified drift and glaciomarine sediments may be included. On the Scotian Shelf, this category corresponds to the Scotian Shelf Drift as defined by King (1970). Elsewhere it has been shown on areas characterized by intense acoustic scattering and irregular surface morphology on seismic profiles (Dale, 1979) or areas described as undifferentiated drift (Grant, 1966; Loring and Nota, 1973).

The wide extent of glacial drift reflects the fact that glaciers covered large parts of the eastern Canadian shelf at various times during the Quaternary Period. The major factor controlling the present distribution of drift has been glacial deposition and post-glacial erosion.

On the Scotian Shelf, an ice sheet apparently advanced to the edge of the continental shelf sometime during the Pleistocene, possibly during the Wisconsinan (King, MacLean, and Drapeau 1972). An end-moraine system that extends 30-40 km offshore is a Wisconsinan-age feature but it is not known whether the feature is a terminal or recessional moraine. During the late-Wisconsinan rise of sea level, glacial deposits above a depth of 110-120 m below present sea level were reworked in the transgressing beach zone. The transgressive erosion effectively removed till from broad shallow areas, including some of the bank tops.

The late Wisconsinan transgression, which began about 15,000 years BP, completely eroded and reworked the unconsolidated sediments across much of the Grand Banks. The level to which sediments were reworked on the Grand Banks is about the same level as that on the Scotian Shelf, 110-120 m below present sea level. Till is generally limited to the channels separating the banks in the Grand Banks area. The terminal position of the Wisconsinan ice in the Grand Banks is not well known.

The seaward limit of till on the northeast Newfoundland Shelf is poorly understood. Grant (1966) has suggested that the thick accumulations of till on the northeast Newfoundland Shelf are terminal or recessional moraines.

The extent of till on bank tops off-shore Labrador is somewhat problematic. The flow of ice on the Labrador Shelf was controlled by topography. The ice advanced to the shelf edge through the saddles that separate the various banks. It is possible that the ice was largely confined to the marginal trough and saddles and did not advance onto the bank tops (Jacques/McClelland Geosciences, inc., 1982).

Thicknesses of glacial drift greater than 60 m are unusual offshore eastern Canada. On the Scotian Shelf, areas where the Scotian Shelf Drift is thicker than 60 m are restricted to a few of the larger submarine end moraines. Till greater than 60 m thick may occur along the edges of the Laurentian Channel in the Gulf of St. Lawrence and further to the east. On the Northeast Newfoundland Shelf, thick till may fill depressions in the bedrock surface and occupy fairly extensive areas. Tills of 100 m or more in thickness are reported (MacLean, in prep.) on the southeastern Baffin Island shelf.

Sand and Gravel

Sand and gravel typically is present on the bank tops and other areas that have been affected by the late Wisconsinan transgression as well as on the Baffin Island shelf where it has been reworked by contemporary currents. On the Scotian Shelf, this category corresponds to the Sambro Sand and Sable Island Sand and Gravel, (King, 1970). Sands and gravels in the Gulf of St. Lawrence and on the Newfoundland and Labrador shelves have been included in this grouping.

On the Scotian shelf, the sand and gravel is typically in a thin veneer less than 10 m thick but locally occurs in pockets up to 80 m in thickness (King, 1970). The sand and gravel commonly overlies till. This is widespread in areas above the marine terrace where the till surface has been modified by marine transgression.

The late Wisconsinan-Holocene transgression was effective in eroding the fine-grained component from exposed glacial deposits and transporting the fine sediments into deeper water. The sand and gravel components were sorted and deposited in beach and sublittoral environments.

The largest expanse of sand and gravel is on Grand Bank where reworking has affected nearly all of the unconsolidated sediments on the southern and eastern portions. Active bedforms in the area indicate that storm waves continue to rework sediments in some areas.

The area of sand and gravel west of Hamilton Bank of the Labrador Shelf may be an area of subaqueous kames and kettles (van der Linden, Fillon, and Monahan, 1976). The outwash deposits forming the kames may be greater than 60 m thick.

On the Baffin shelf, winnowing by bottom currents appears to be a factor in the modification of surficial sediments (MacLean, in prep.).

<u>Competent Fine-grained Sediments</u>

Competent fine-grained sediments (stiff to hard silts and clays) have been shown only in the Laurentian Channel, Whale Deep and on Saglek Bank. Although the surface distribution of these materials is extremely limited, there are probably extensive deposits of competent fine-grained sediments in the subsurface. The basal part of the Emerald Silt, (King, 1970) a fine-grained glaciomarine deposit, is probably a competent material throughout most of its extent. The outcrop area of the basal Emerald Silt is restricted to the outer margins of some shelf basins and has not been resolved.

<u>Weak Sediments</u>

Significant accumulations of soft clay, loose silt, or loose sand have been classified as weak sediments. Areas shown as weak sediments generally have more than 3 m of weak sediments at the seafloor. Layers of soft clay, loose silt, or loose sand that may be present in the subsurface underlying competent sediments could not be mapped with the available data.

Weak sediments typically occur within topographic depressions on the continental shelf. On the Scotian Shelf, this category corresponds to the Emerald Silt and LaHave clay (King, 1970). In some areas, this category corresponds to "acoustically transparent" sediments described by various workers. Where no surficial geologic maps were available, the areal extent was extrapolated from the topography, (JMGI, 1982).

The largest continuous expanse of weak sediments shown on the JMGI mapping occupies the Laurentian Channel, Esquiman Channel, and Anticosti Channel. It occurs within scattered depressions on the Newfoundland Shelf and within many of the bays off Newfoundland. Weak sediments are restricted almost exclusively to the marginal trough and saddles on the Labrador Shelf. Weak sediments occur within most depressions and basins on the Scotian Shelf. On the Baffin Island shelf, weak sediments are present in Frobisher Bay and Cumberland Sound.

The weak sediments accumulated principally from two sources. Much of the fine-grained sediment that directly overlies and interfingers with till was deposited in a proglacial environment. King (1970) suggests that most of the Emerald Silt was deposited from floating ice that carried a wide range of particle sizes. In addition to proglacial deposition, fine-grained sediments have accumulated in the basins as a result of post-glacial erosion. During the late Wisconsinan transgression, clay and silt were winnowed from the banks and accumulated in basins. Clay may still be accumulating in the basins as a result of winnowing by storm wave and currents but at a much slower rate than during the last marine transgression.

Steep Slopes

The areas of steep slopes are shown on Figures 2.2 to 2.6. Within the areas covered by weak sediments, slopes of greater than 3 percent are indicated. Slopes greater than 6 percent are indicated for all other areas. The term "steep slopes" is quite relative; on land, such gentle slopes would rarely be subject to slope failure, however, submarine slope failures on slopes less than 1 percent have been documented where sediments are highly unstable. It appears unlikely that slope failure will be a significant concern where slopes are less than those indicated as "steep" in this report. However, the stability of these slopes cannot be definitively evaluated with the available data.

2.2 Geologic Features and Conditions

Many kinds of geologic features and conditions of potential engineering significance exist on the continental shelf and slopes of Eastern Canada. These features include submarine landslides, mudflows, faults, pockmarks, gas at relatively shallow depths, migrating seafloor sediment, extremely hard or soft seafloor, locally irregular seafloor, relatively steep slopes, iceberg furrows, submarine permafrost, gas hydrates, and buried channels. Man-made objects on the seafloor, such as shipwrecks, pipelines, and cables, also are of potential engineering importance.

The significance of a specific geologic feature or condition in a given situation depends on a number of factors including the design of the proposed structure, the types of activities planned in the area, and the location of the geologic feature. In some cases, a particular feature may be a hazard, and in others, merely an engineering constraint. Typically, marine-engineering geologists first identify a feature or condition as a *potential hazard* and then geotechnical and structural engineers evaluate it to determine its technical and economic ramifications. The engineer will finally classify the feature as either an engineering *constraint* or as an actual *hazard*. These terms may be defined as follows (modified after Kraft *et al.*, 1978):

A *potential hazard* is a feature or condition with potential for causing serious safety, equipment, or pollution problems, unless potential effects are prevented by proper design and construction.

An *engineering constraint* is a feature or condition that presents difficulties for safe, environmentally sound engineered construction; however, its potential effects can be mitigated economically by proper design and construction.

A hazard is a feature or condition that can cause serious safety, equipment, or pollution problems; its effects cannot be easily or economically mitigated by engineering design.

Clearly, the definition of a hazard is chiefly a matter of economics. That is, structures can be designed and constructed to withstand the effects of most geologic conditions, regardless of their severity, if cost is not a consideration.

Brief descriptions of potentially significant offshore features and conditions are presented in Appendix 1. Because of the variability inherent in most geologic conditions, engineering assessments presented are intended as only general guidelines; the engineering significance of specific geologic features and their effects on safety can only be determined on a site specific basis.

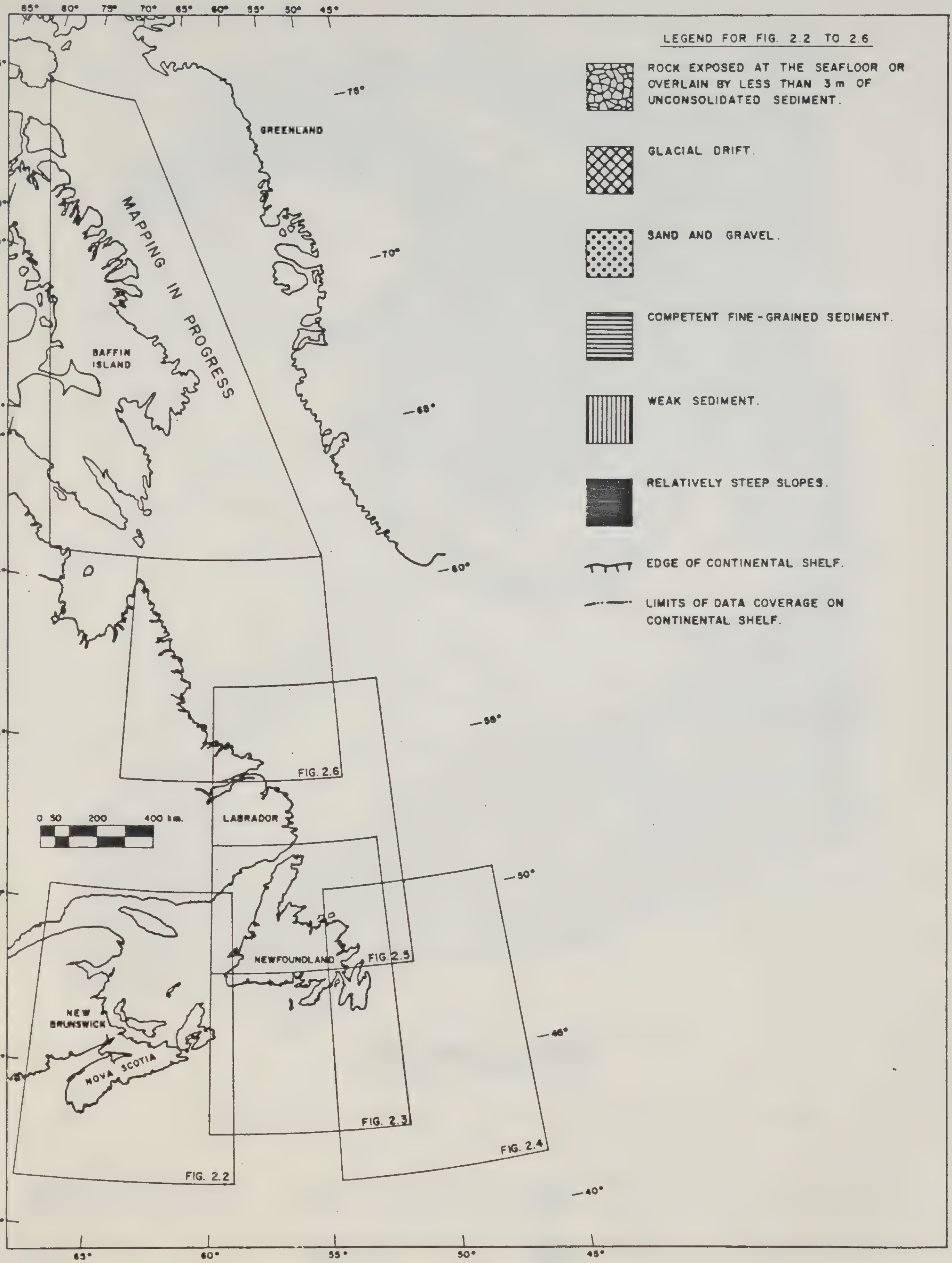


Figure 2.1: Key Map and Legend

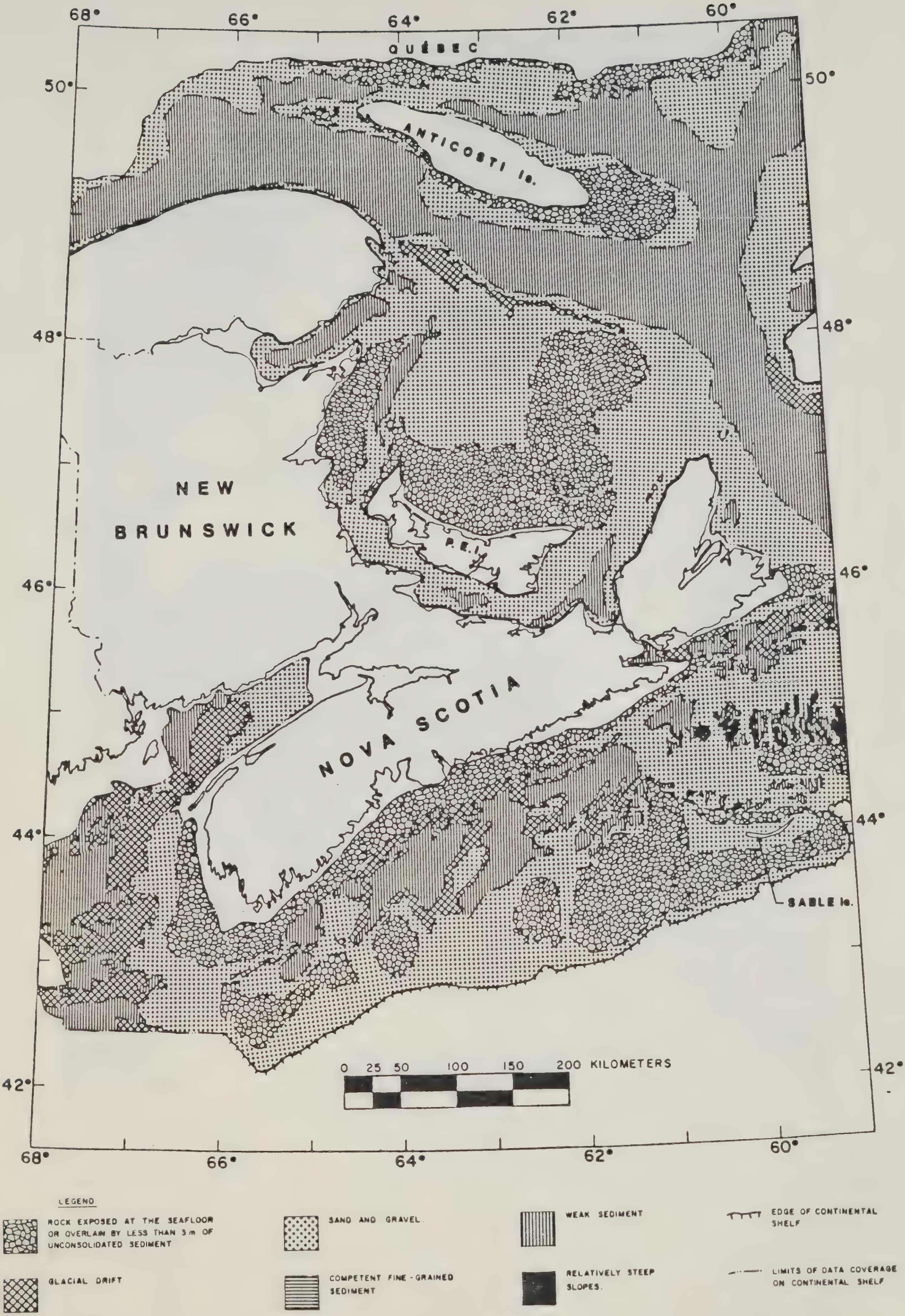


Figure 2.2: Interpreted Seabed Sediments (after JMGI, 1982)

Figure 2.3: Interpreted Seabed Sediments (after JMGI, 1982)

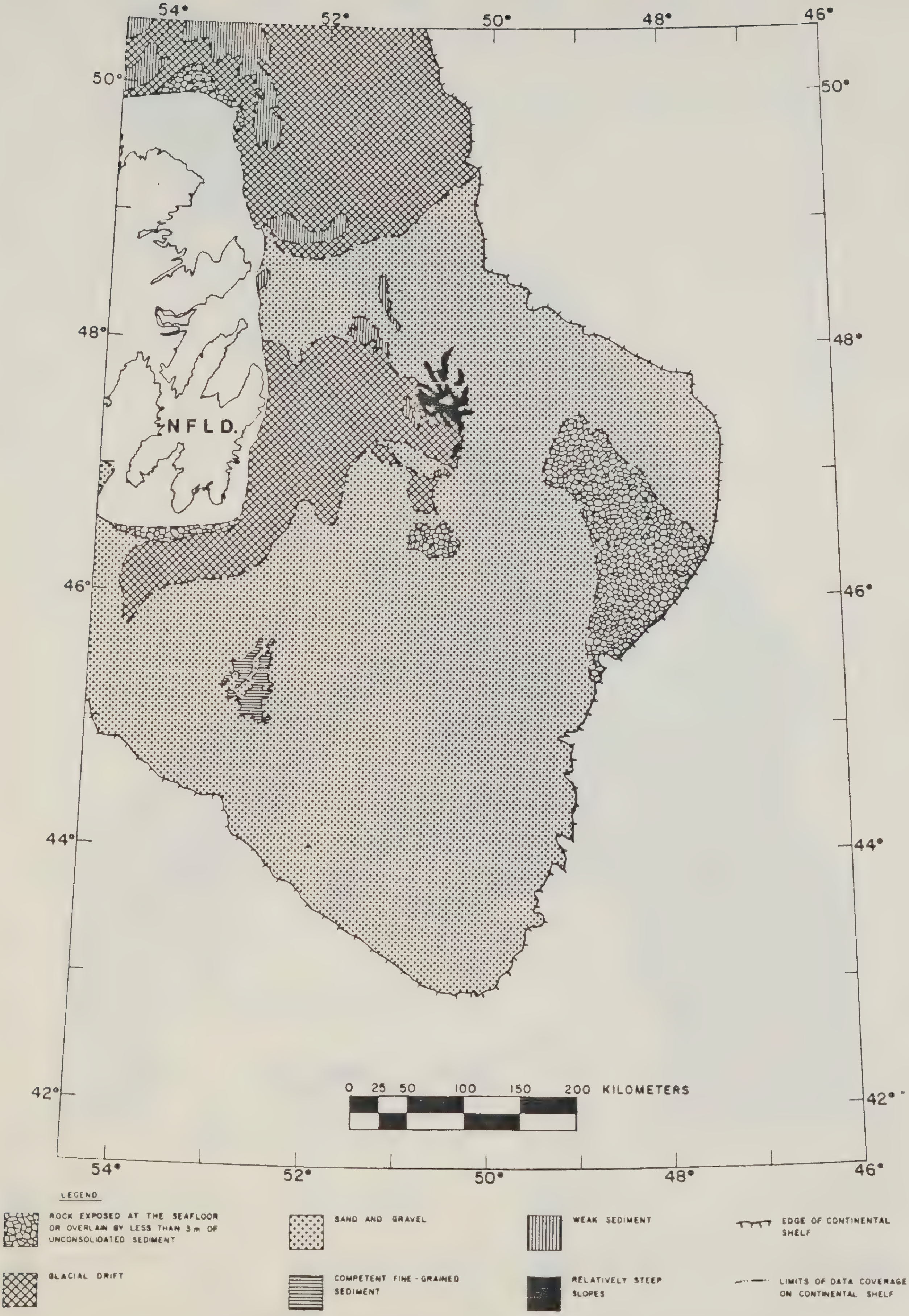


Figure 2.4: Interpreted Seabed Sediments (after JMGI, 1982)

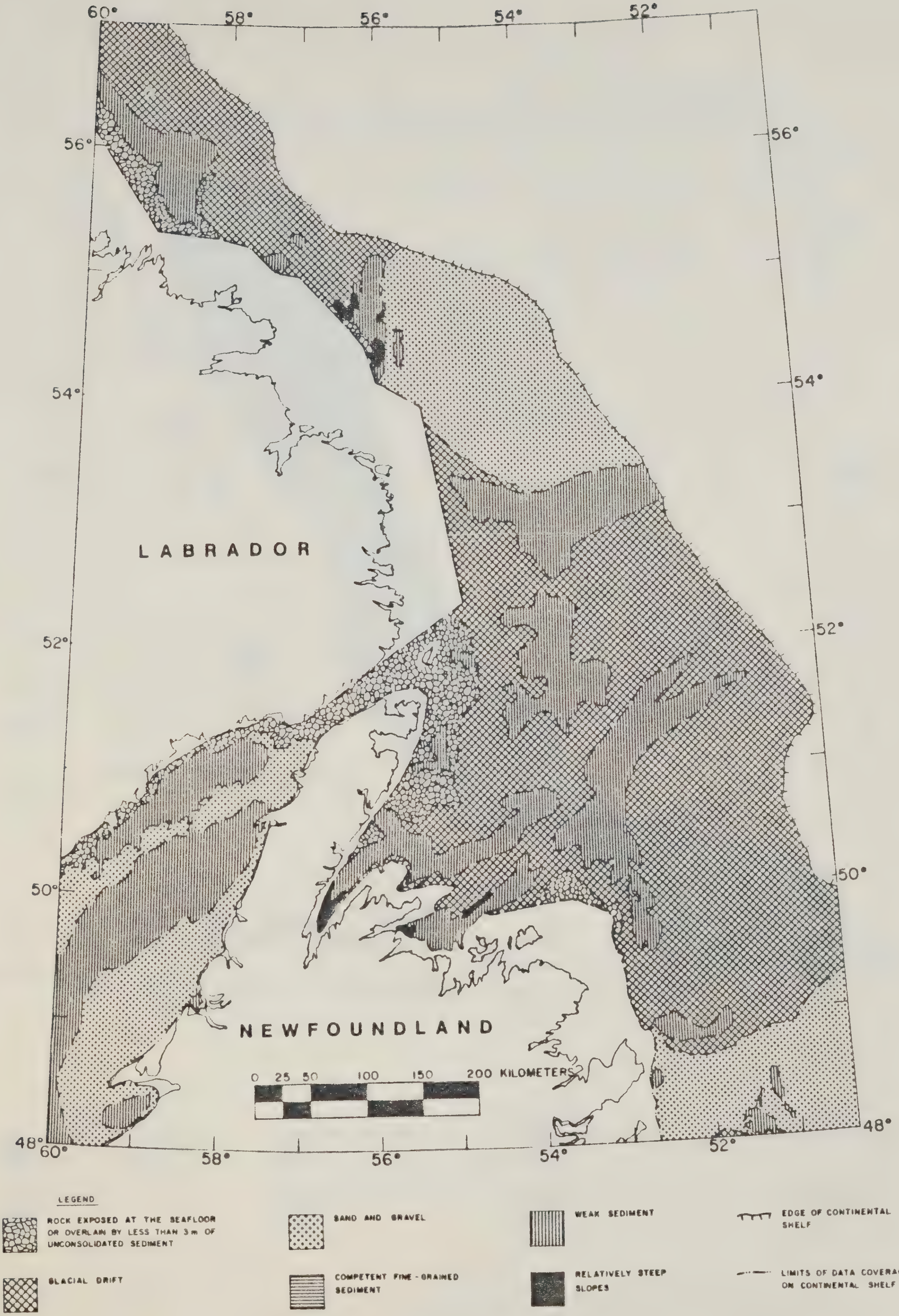


Figure 2.5: Interpreted Seabed Sediments (after JMGI, 1982)

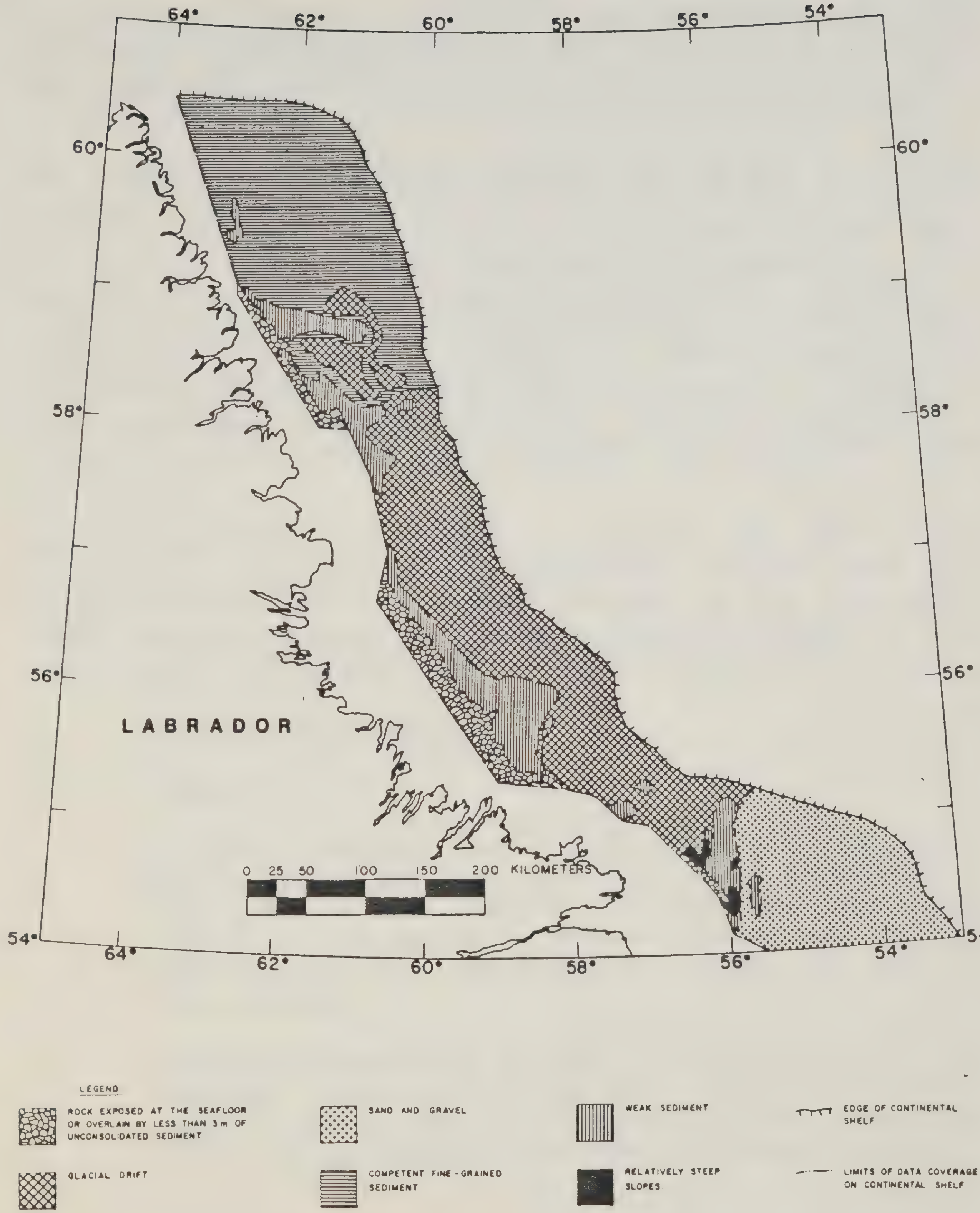


Figure 2.6: Interpreted Seabed Sediments (after JMGI, 1982)

3. DRILLING EQUIPMENT AND SEABED INTERACTION

Eastern Canada offshore exploration and delineation drilling operations primarily involve the use of drillships, semi-submersible drilling rigs and jack-up drilling rigs. Each of these units interacts, to varying degrees, with the seabed.

The interaction is extremely significant in the case of jack-up rigs which depend completely upon the seabed and underlying materials for foundation support. Although less critical than for jack-up rigs, seabed conditions are significant for drillships and semi-submersibles which use anchors for mooring. (Seabed conditions would not be significant in the case of units equipped with a dynamic positioning system capable of maintaining the unit on location without anchors). A somewhat less significant interaction which is, however, common to all types of drilling units occurs between well conductors and the seabed.

The following sections describe in detail how jack-up rig foundations, anchors, and well conductors, interact with the seabed. State-of-the-art methods of analysis are discussed. Major emphasis is given to jack-up foundations because of the severe safety hazard associated with a foundation failure.

3.1 Jack-up Rig Foundations

3.1.1 General

A jack-up drilling unit is a platform with legs which can be raised and lowered. After being floated to a site with its legs elevated, the legs are lowered and jacked into the seabed to produce a foundation and the once-floating hull is raised to provide an elevated work platform.

Foundation systems for the units are of two types: the mat type, which has three or more legs supported by a common foundation base; and the footing type, which has three or more footings (spud cans), each supporting an

individual leg. Mat-supported rigs have been developed to operate in areas with very soft seabed sediments while individual footing-supported rigs can more readily accommodate site variability. About 75 percent of jack-up units are supported by individual footings and all the rigs employed to date offshore eastern Canada have had footing-type foundations.

3.1.2 Moving on or off Location and Preloading

One of the most critical phases in jack-up rig operations occurs when the rig is being moved on or off location. For most rigs, this phase includes preloading of its foundation. Accident records show that about one-third of all major non-well accidents occur while a rig is being transformed from a moving, floating vessel to a fixed, bottom-supported, offshore structure, or vice versa.

Responsibiity During Rig Moves

Rig owners have recognized the importance of the rig move, and many have trained personnel called "rig movers" to oversee this operation. The rig movers are familiar with the mechanics of buoyancy for the rig and with the jacking equipment and procedures. The general role of the rig mover is to be in charge of all operations on the rig while moving off location, towing to a new location, jacking out of the water, preloading, and jacking to operational height.

Moving Onto Location

After a jack-up rig is positioned at a proposed site, the legs are jacked down, causing each footing to penetrate the seafloor until the bearing capacity of the soil equals or exceeds the submerged weights of spud can and leg. Then, as a result of continued operation of the jacking system, the hull begins to lift out of the water. As buoyant forces supporting the hull are

decreased, the operational light ship weight and the variable load are transferred to the foundation, and the legs continue to penetrate as the footing load increases. A preloading procedure is then carried out to secure final penetration of the legs. After the preloading operation has been completed, the rig is jacked up to its operational height, typically 10 to 20 m above sea level.

Preloading

Foundation preloading has been widely used as a method of proof testing for various types of foundations and has been adopted as standard operating procedure for most footing-type jack-up units. The purpose of preloading a jack-up foundation is to force additional penetration of the footings to a level where the total bearing capacity exceeds - by an acceptable margin of safety - the highest anticipated load associated with a selected design storm condition. There are no clear guidelines, however, as to what is an acceptable margin of safety for preloading. (Margins of safety are discussed in Section 3.4.) Preload level is normally established by the rig designers, owners and insurers. The preloading capability of jack-up units varies widely, depending upon the number of foundation elements and the design characteristics of the unit. The most common method of preloading is by ballast.

Ballast Preloading - For most three-leg jack-ups in operation today, preloading is accomplished by pumping seawater selectively into a series of holding tanks, maintaining approximately equal loading on all legs during the process. While some rig operators seek to maintain a minimum 1.5 m air gap throughout the preloading period by jacking the hull up the legs as footings penetrate, most rig owners try to protect the longevity of the jacking mechanism by prohibiting operation of the jacks against partial or full preload.

Prohibition of jacking during the preload operation can create a difficult situation if large leg movements occur under the preload increment. Such large movements can exceed the air gap and partially submerge the hull. This situation requires the rig mover to dump ballast before preloading is complete. He can then raise and relevel the hull at the proper elevation and resume preloading. In anticipation of this time consuming problem, rig movers sometimes raise the hull more than 1.5 m out of the water prior to preloading. This action, however, can significantly endanger the rig unless a prior geotechnical investigation has clearly indicated that there is no danger of sudden excessive footing movement.

Generally, the preload is held for a minimum time of 2 to 4 hours after all footing penetrations have ceased. (Young et al., 1982)

Moving Off Location

Upon completion of drilling operations, the jack-up rig is prepared for transit under the direction of the rig mover. Initial preparations are directed towards transforming the rig from a drilling platform into a "seaworthy" vessel. The onboard variable load is computed and shifted (or reduced) so that the rig will be trim when floating.

The unit is then jacked down into the water with minimal tilting so that the buoyant forces on the hull apply tension to the legs and begin to lift the embedded spud cans. When the spud cans break loose from the soil, the legs are alternately raised to their seagoing position, and towing begins.

3.1.3 Foundation Loads

After a jack-up rig has reached location and raised its hull out of the water, its foundations are subjected to two types of loads: gravity loads and environmental

loads. Gravity loads consist of the operational light ship weight and a variable load. Environmental loads include some combination of wind, wave, current and occasionally ice forces. Figure 3.1 illustrates these various forces acting on a mobile jack-up drilling unit. During a storm, overturning moments caused by wave and wind forces may increase the vertical load on a footing by as much as 35 to 50 percent of the gravity load. The horizontal footing load during a storm may range from about one-tenth to one-third the magnitude of the total vertical footing load.

Gravity Loads

Gravity loads are usually known with greater certainty than environmental loads. With a careful inventory of equipment, materials, and supplies, the total gravitational load can be calculated with a two percent accuracy.(McClelland *et al.*, 1981)

Environmental Loads

The foundation loads known with the least accuracy are the environmental loads, because they are estimated based on statistical data or probability for a specific geographic region. Rigs designed in conformance with certification rules in a specific area may not be suitable for operation in more severe environments.

Wave: The most significant environmental loading comes from wave action. It can produce about 55 to 65 percent of the total lateral loading. (McClelland *et al.*, 1981). The design wave is the one that produces the most severe loads on the structure, taking into account the shape and size of the structure, water depth, etc. For some areas offshore Eastern Canada, design waves are as high as 30 m.

Wind and Current: Wind loading usually represents 25 to 35 percent of the total lateral loading. (McClelland *et*

al., 1981) Current forces in some areas of the world can be significant and must be considered. For instance, currents of 4 knots are not unusual in the Bay of Fundy. A typical design current is about one knot, which can contribute as much as 10 percent to the total lateral load.

Ice: Both sea ice and icebergs are potential sources of environmental loading in portions of the eastern Canada offshore. Some sea ice loads may be allowed for in rig design but seasonal operation is expected to be the more normal procedure. Exploration drilling rigs are generally not designed for iceberg impact loads; monitoring, towing and abandonment procedures are used for avoidance.

Earthquake: Earthquake effects are not normally considered at exploration drilling sites because of the relatively short period that a rig is present. Even in the design of permanent offshore structures where earthquake loading is included, it is not considered to act simultaneously with storm loadings. Knowledge of the frequency and magnitude of earthquakes in the eastern Canada offshore is limited due to the relatively short period over which seismic monitoring has been undertaken. Although various models of seismicity on the Eastern Canada offshore have been proposed, a maximum value of the peak horizontal acceleration with a probability of exceedence of 10% in 50 years equal to 0.32 g is common to many (Basham *et al*., 1983).

3.1.4 Foundation Problems

Jack-up drilling units, especially of the footing-supported type, have a poor safety record in comparison with other structures which interact with the seabed. Based on non-well accidents causing more than $500,000 damage each, their annual accident rate, expressed as a percent of the active fleet, is twice as severe as any other mobile rig group (2.7 percent versus 1.4 for semi-submersibles) and more than an order of magnitude worse than fixed platforms (2.7 versus 0.1), (McClelland *et al*.,1981).

Figure 3.2 shows the yearly variation in this rate for the period 1970 - 1980 and also indicates the rate of "leg accidents". The leg accidents include soil foundation failures and also some instances of structural failure. However, they do not include any of the accidents in which a rig on location was destroyed by storm or hurricane -- accidents which may have begun as foundation failures. The figure shows that more than 1 percent of the total rig fleet (about 375 in 1982) annually experiences a leg accident. This percentage suggests that 3 or 4 major accidents of this type will occur in any year. Assuming that a jack-up unit moves four times annually, the failure probability is about 1 in 400 at each location.

The following discussion describes five different types of foundation problems or accidents, all posing some risk to life, and all associated with some inadequacy in soil-foundation interaction. Some of these are more serious than others from the standpoint of personnel safety and serious property loss.

Punch-through During Preload

At occasional locations, the subbottom soil profile includes a strong layer of soil (with a high bearing capacity) overlying a weaker layer (with a lower bearing capacity), as illustrated in Figure 3.3. This situation can be of great danger if the bearing capacity of the hard layer is sufficient to allow the unit to elevate (Load Condition A, Figure 3.3), but is not sufficient to carry the preload (Load Condition B). Then, when the increasing preload reaches the maximum resistance of the hard layer, a spud can (usually only one) will punch through the hard layer and plunge rapidly into the underlying weak layer until adequate resistance is encountered at some lower level.

It is important to recognize that the person directing a ballast preload operation has little control once punch-through begins, since the applied load cannot immediately be removed or reduced. The magnitude of vertical movement and resulting tilt depends upon the depth to more resistant soil and, in some cases, on the height of hull above sea level when movement begins. The latter dimension is significant, because the footing load will diminish once resubmergence of the hull begins. In some cases, quick action on the part of the operator can minimize damage due to a punch-through if he jacks down the plunging leg and raises those on the high side, compensating for the tendency of the rig to tilt. To count on this procedure, though, is hazardous. In a 1980 accident, illustrating the devastating swiftness of such failures, the three-legged jack-up Triton III had just applied full preload at a location off the Texas coast when one leg plunged 8 metres in less than 30 seconds. Fortunately, no lives were lost, but reports of the accident indicate that there were four personal injuries and substantial property damage.

There are a variety of geologic conditions that can produce the hazardous subbottom sequence of hard layer overlying weaker layer. Some of these are as follows:

- On a continental shelf composed of Pleistocene sediments that were exposed to weathering during he last period of lowered sea level, there can be a desiccated and hardened clay crust overlying poorly oxidized and weaker clay of the same age.

- On shelf areas transversed by glaciers, there can be clay layers that were overconsolidated by ice loading underlain by weaker clay layers that remained frozen and therefore resisted consolidation during the period of ice loading.

- On Pleistocene shelves, relict beach or strand plain sands may overlie poorly oxidized clays.

Available seabed data is not sufficient to predict the occurrence of these conditions but methods are available by which their presence can be determined. This is discussed further in subsequent sections. The global record of jack-up rig accidents confirms that conditions which allow punch-through are widespread.

Excessive Storm Penetration

Under ideal conditions, the preloading operation serves as a "proof test" of the footings by subjecting them to loads in excess of any they are likely to encounter during storm conditions. However, depending upon the anticipated storm magnitude at a proposed location, a specific jack-up unit may not have the preload capacity to provide an adequate margin of safety. Under these circumstances, a calculated risk sometimes is taken that a severe storm will not be encountered while the rig is on location. Whether for this reason or because storm loads were underestimated, a storm is sometimes experienced that loads the footings in excess of preload, as illustrated by Load Condition C in Figure 3.4. Additional uncontrolled penetration of the footings will result. The magnitude of the additional penetration may be large enough to cause severe damage to the rig, especially if punch-through occurs. Detailed knowledge of the foundation soils allows an estimate of the additional penetration that may occur under the storm load, and therefore an assessment of the risk involved may be made. The prediction of storm loading is outside the scope of this report.

Foundation Instability Due to Scour

A foundation failure may also be brought on by seafloor scouring around the footing. Shallow water sites (less than 30 m) with granular soils at and near the seafloor are especially susceptible to scour if strong bottom currents are present. There have been many instances of scouring problems with jack-up rigs supported by individual footings. In one of these, scour in excess of 3 m caused major problems for Odeco's Gulftide while operating off Sable Island in 1977 (Song et al.,1979).

The hazard associated with scour develops primarily because footing tip penetration under preload in sands is generally less than 3 m, leaving the maximum cross-sectional area of the footing close to, and sometimes above, the seafloor. Scour undermines the footing, resulting in a reduced bearing area. Reduction in depth of embedment also reduces footing bearing capacity. Under these influences, the footings will settle until the contact area and bearing capacity are once again adequate to support the footing load. If scour is more severe for one or two footings, the resulting unequal settlement and tilt can be hazardous to the stability of the rig.

Existing Depressions

A jack-up rig could locate at a site where depressions exist in the seafloor. These may be naturally occurring, such as pockmarks, or may have been caused by a rig previously installed at the location. In areas of these depressions, there is the possibility of differential leg penetration, sliding of the structure into the depression, or punch-through of a leg affected by a depression. The problems associated with a rig jacking up near or in an existing depression depend upon the nature and dimensions of the depression, rig characteristics and the soil type. Effective methods of mitigating the effects of depressions thus depend upon site specific conditions.

Seafloor Instability

Many offshore areas around the world are susceptible to seafloor instability induced by gravitational forces on oversteepened slopes or by differential bottom pressures from ocean waves. Resulting mass movements of seafloor sediments can produce destructive lateral forces on any structure caught in the path of such movements. Much attention has been given to this localized but severe problem since Hurricane Camille damaged or over-turned

three pile-supported platforms near the Mississippi delta in 1969 (Sterling and Strohbeck, 1973). Mass movement of seafloor sediments may pose a hazard on the continental slope of eastern Canada (Piper and Wilson, 1983) as well as on steep slopes on the shelf.

3.1.5 Avoiding Foundations Problems

Foundation problems which relate to safety may be grouped into three categories: Rig unsuitable for the site, procedural error, and regionally unstable site. Published accident records suggest that the commonest cause of foundation accidents is the use of rigs unsuitable for the site. A rig that is "unsuitable" in this context could be one with insufficient leg length, a footing area too small to avoid punching through a hard layer, or a footing system unable to force safe penetration into an erodable surface layer.

To avoid placing a mobile jack-up unit at a site where the equipment is not suitable, the operator must have advance knowledge of subsurface conditions at the site and how these conditions relate to the proposed unit's performance. Available informaton on the characteristics of seabed sediments is not sufficient to provide this knowledge. As discussed later, geotechnical investigations at specific sites can provide the necessary data for quantifying the risks and for making a rig selection that will reduce those present.

Classical analytical procedures used in designing the foundations of structures can be adapted to predict the bearing capacity of jack-up unit footings. Since foundations for jack-up rigs are generally not custom designed for a specific site, the object of analyses is to develop a curve of footing penetration versus footing load, such as shown in Figures 3.3 and 3.4, in order to determine if the rig is suitable for the site. Analytical procedures that have been shown to provide

satisfactory predictions of foundation bearing capacity performance include: Skempton (1951) and Gemeinhardt and Focht (1970) for continuous clay deposits; Vesic (1975) for continuous granular deposits; Brown and Meyerhof (1969) and Hanna and Meyerhof (1980) for layered soil systems.

Potential scour problems can be identified from boring data or from geologic evidence. In the past, scour protection has been sought by placing sand bags, oyster shells, gravel, or other scour resistant materials around the edge of the foundation. These techniques may also be used today, but other methods are probably more effective. In areas prone to severe scour, the problem may be alleviated by using footings designed for a high bearing pressure during preload and by employing an airlift waterjet system to achieve penetration of at least 5 m below the seafloor prior to preloading. After jetting in and applying the preload, which acts to densify soils loosened by the jetting process, it is possible to achieve theoretical bearing capacities well in excess of the preload. Based on model tests, a "cookie-cutter" footing design is expected to be effective in prevention of undermining due to scour, (Winkel, 1981).

The second category, procedural error, is outside the scope of this report but is noted because it can affect foundation safety. Although not discernible from published records, procedural errors such as application of insufficient preload, incorrect estimation of gravity or storm loads, excessive elevation of the hull prior to preloading, and improper balancing of leg loads while setting up or when preparing for a storm are widely believed to be at least a contributing cause in some foundation accidents (National Research Council, 1981). It therefore appears that better instrumentation and

predictive techniques for estimating loads, and more specific attention to foundation problems in operating manuals are of importance in achieving and maintaining high levels of personnel performance with regard to foundation safety.

Because severe mass movements of seafloor sediments are relatively unique and infrequent, this third category is seldom considered with respect to mobile drilling units, which usually occupy a site for only a short period. Geophysical surveys, particularly side scan sonar, can provide identification of instability features so that they can be avoided.

3.2 Anchors

3.2.1 General

On offshore drilling vessels which utilize mooring techniques for maintaining position, catenary anchoring systems as shown in Figure 3.5 are almost always used. These systems consist of mooring lines (chain or wire rope) with sufficient length and weight to cause the line to remain tangent with the seafloor at or before the anchor even under maximum line tension. This arrangement permits the anchor to develop its maximum holding power by preventing uplift on the anchor.

In addition to catenary anchoring systems, the offshore petroleum industry also uses tension-leg anchoring systems and single anchor-leg systems, but these have more specialised purposes and are not routinely used in exploration work.

3.2.2 Anchor Design and Performance

The design and performance of anchors depend on a number of considerations among which the following are of major importance:

° Magnitude and direction of loading (depends on type of structure, type of anchoring system, water depth and environmental conditions);

° Type of loading (static or cyclic, short or long term);

° Soil conditions (stratification, soil type and strength characteristics);

° Seabed topography (uneveness and slope, boulders and sandwaves);

° Anchor handling and installation aspects;

° Safety requirements and consequences of failure.

The broad variation in many of these considerations has led to the development of a number of different anchor types and sizes, each with its specific advantages and disadvantages. The three main types capable of developing high holding capacity are fluke or embedment anchors, pile anchors and gravity anchors. Other types such as deep embedment plate anchors and suction anchors have been developed but their capacity is generally too small for anchoring of drilling units. Pile and gravity anchors have more application for permanent production facilities while fluke anchors are the most common in exploration drilling. (Olsen et al.,1982).

Fluke Anchors

Fluke anchors include the commonly used ship anchors as well as the modern rig anchors developed during the last 10 years (Figure 3.6). These generally consist of a shank through which the load is applied and flukes which are constructed to make the anchor penetrate into the soil and thus mobilize the weight and strength of the soil. Additional parts such as tripping palms and stabilizer bars have been used on several anchor designs

to encourage embedment and improve the stability against rotation and pull-out.

Model, medium scale, and large scale tests have been performed over the years to improve the capacity and reliabilty of fluke anchors. Some of these test programs led to development of new anchor designs. (Figure 3.7) Bruce, Hook, Boss, Stevin, Doris, and Delta Flipper are examples of these new designs. The Danforth and LWT anchors or improved designs like the Moorefast and Stato are most frequently used for semisubmersible drilling rigs.

The holding capacity of fluke anchors depends on the soil conditions, the fluke area, and the penetration depth. Vertical load components generally will reduce the holding capacity seriously.

Penetration ability depends on fluke angle and soil type. A fluke angle of about 30° for sand and about 50° for clay is reported to give the best results (Olsen et al.,1982). A streamlined design of all the anchor components is essential.

Fluke anchors are installed by lowering to the seabed by a pennant line, followed by dragging of the anchor along the seabed until the flukes penetrate sufficiently deep to mobilize the required resistance. If the anchor is unstable during dragging; that is, if it rotates about the dragging direction, the anchor might be pulled out after a certain dragging distance and never achieve the required holding power. Anchor stability is thus important with respect to safety of an anchoring system. An unstable anchor which is overloaded during one or a few wave cycles might be pulled out and lose most of its holding power.

The prediction of holding capacity is based on empirical relationships between weight and soil type, experience from previous installations, and extrapolations from small scale tests. (Le Tirant, 1979).

Verification of holding capacity is generally based on proof testing. The relevance of this type of load test which only incorporates a short-term static pull or dragging at a relatively high velocity is open to debate. The effect of the cyclic load component that unavoidably will be present under storm loading conditions is not taken into account and represents a factor of uncertainty. Proof loading of heavy anchors becomes both impractical and very costly and it would, from a geotechnical point of view, be more satisfactory if the holding capacity predictions could be carried out based on soil mechanics principles. Development work in this direction is underway at a number of institutions. While the ability to predict holding capacity for particular soil conditions would not eliminate the advisability of proof loading, it would provide a basis for the selection of type and number of anchors at a given site.

3.3 Well Conductors

3.3.1 General

The main function of conductor pipes and casings is for well control during drilling and as such they are more related to down-hole considerations than to seabed conditions. They do, however, interact with the seabed materials since it is from these materials which the conductor pipe and the upper portions of the conductor casing derive their support.

3.3.2 Conductor Design and Performance

The loads which conductors are required to resist include gravity loads from self-weight and well-head equipment such as blowout preventors, and imposed loads from marine risers, waves and currents. The loads are generally more severe in the case of floating drilling units where well-head equipment is located on the seafloor than for jack-ups where the equipment is located on the structure.

Axial loads on conductors are transferred to the seabed materials mainly by shaft friction. End resistance may be small due to the influence of drilling conditions.

Analysis of axial capacity can be made using soil mechanics methods for drilled and grouted piles (API, 1982). The installation of grouted or jetted pipes under offshore conditions can, however, result in considerable differences between predictions and performance.

Lateral and flexural loads on the conductors are resisted by horizontal soil reaction stresses. Soil mechanics procedures developed for the analysis of laterally loaded piles (Matlock and Reese, 1960) can be used for analysis and design. The lateral resistance of the soil near the sea floor is significant to the analysis and the effects of scour and soil disturbance on this resistance during conductor installation have to be considered.

3.4 Margin of Safety

As for structures on land, the design and use of exploration drilling equipment components which interact with the seabed require adequate margins of safety against failure and unserviceability. The requirements for the safety and serviceabilty of offshore structures, however, differ considerably from those on land. Offshore drilling equipment components are subjected to larger and less predictable environmental loads and their design and use is based on more difficult soil explorations and more complex soil behaviour under fluctuating loads.

In offshore operations, margins of safety, with respect to seabed conditions, are required to account for the uncertainties and the variabilty of the soil conditions, the approximations in any analyses employed, and the effect of cyclic loading. A margin of safety is also

required to provide for uncertainties associated with environmental loads which can only roughly be estimated from probabilistic loading and load effects spectra.

Margins of safety are introduced into the analyses of seabed-structure interaction through the use of factors of safety. Factor of safety may be defined broadly as the ratio of resistance of the seabed-structure system to the applied loading effects. Offshore foundations are generally designed with a minimum overall factor of safety of 2 under normal operating conditions and 1.5 under extreme environmental loading. For foundations on land, minimum overall factors of safety of 3 under normal and of 2 under maximum loading conditions are normally used. (Meyerhof, 1982) The use of lower factors of safety offshore implies an increased risk of failure of offshore foundations compared with foundations on land. It has been estimated that the probability of failure of an offshore foundation is in the order of 10 times greater than the failure of a foundation on land. (Meyerhof, 1976). In order to provide margins of safety comparable to those on land, the factors of safety used offshore would have to be increased.

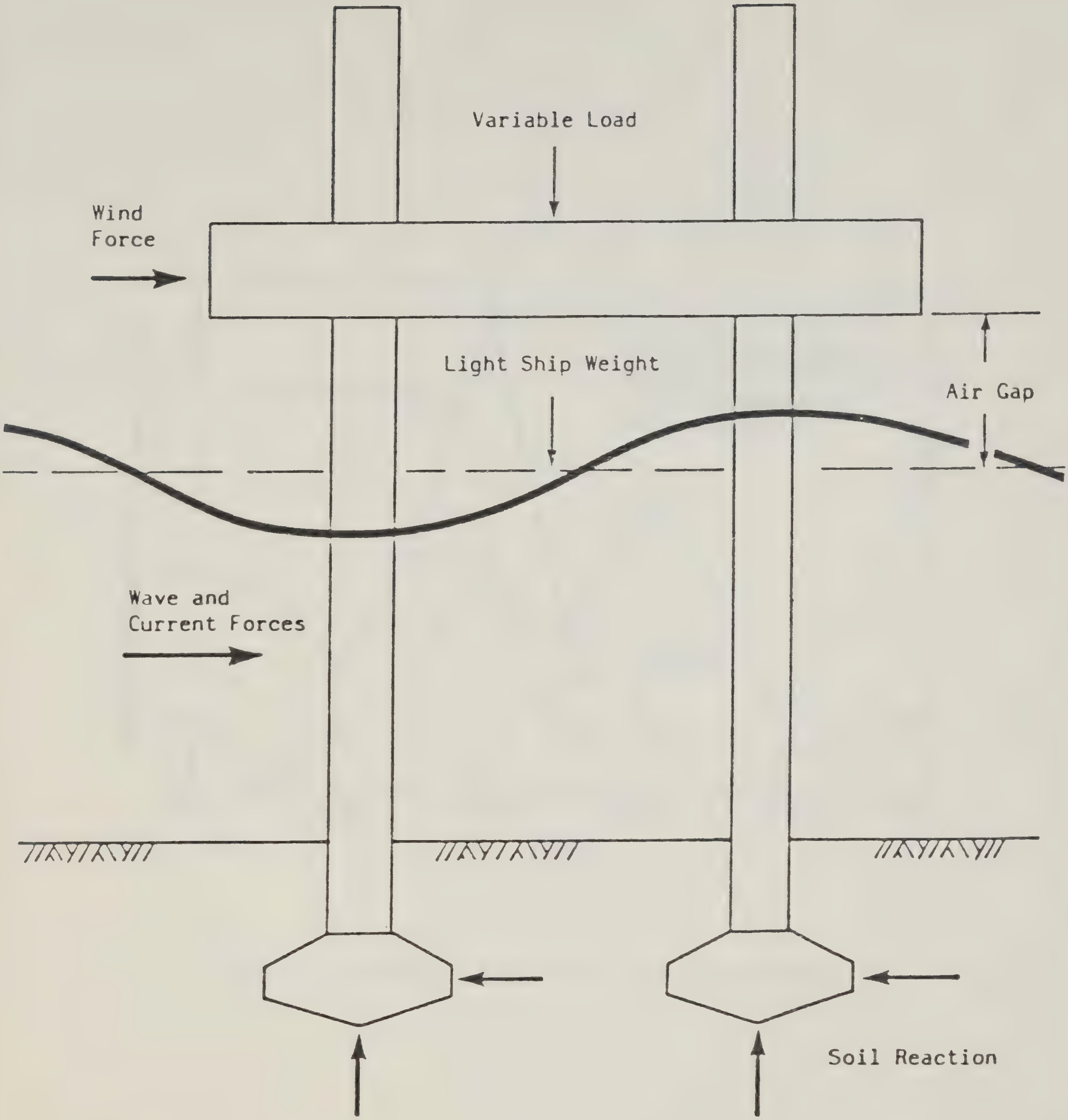


Figure 3.1: Loads on a Jack-Up Rig

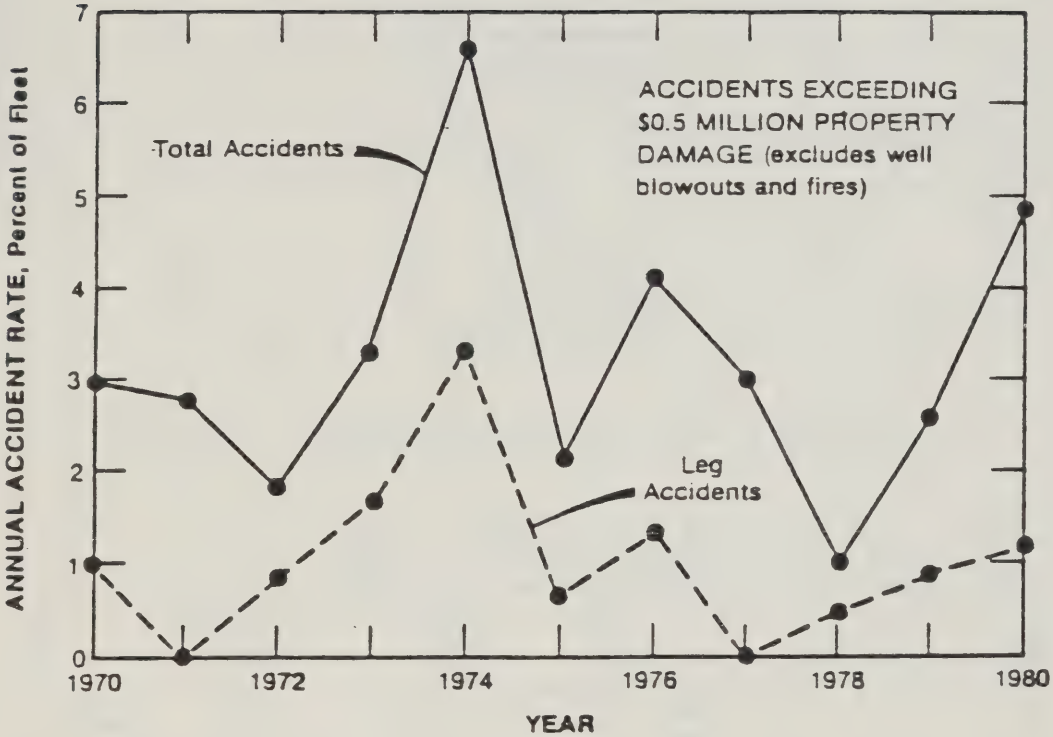


Figure 3.2: Annual Accident Rate for Jack-Up Rigs

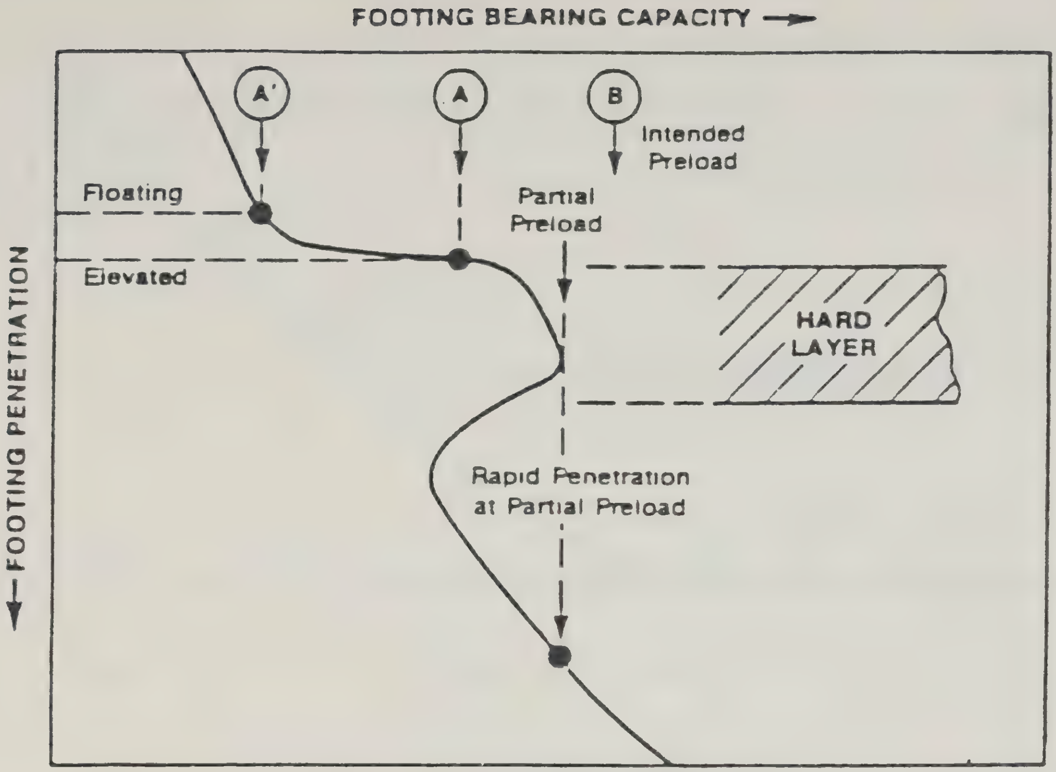


Figure 3.3: Punch-Through Failure During Preload

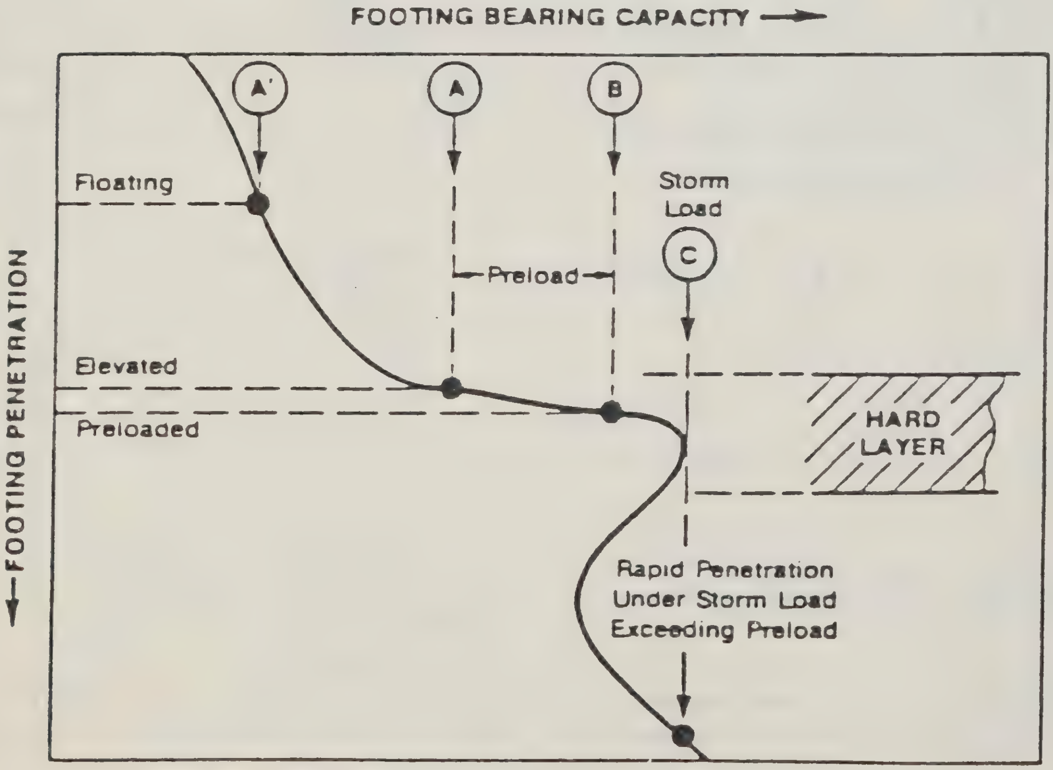


Figure 3.4: Punch-Through Failure Due to Storm Overload

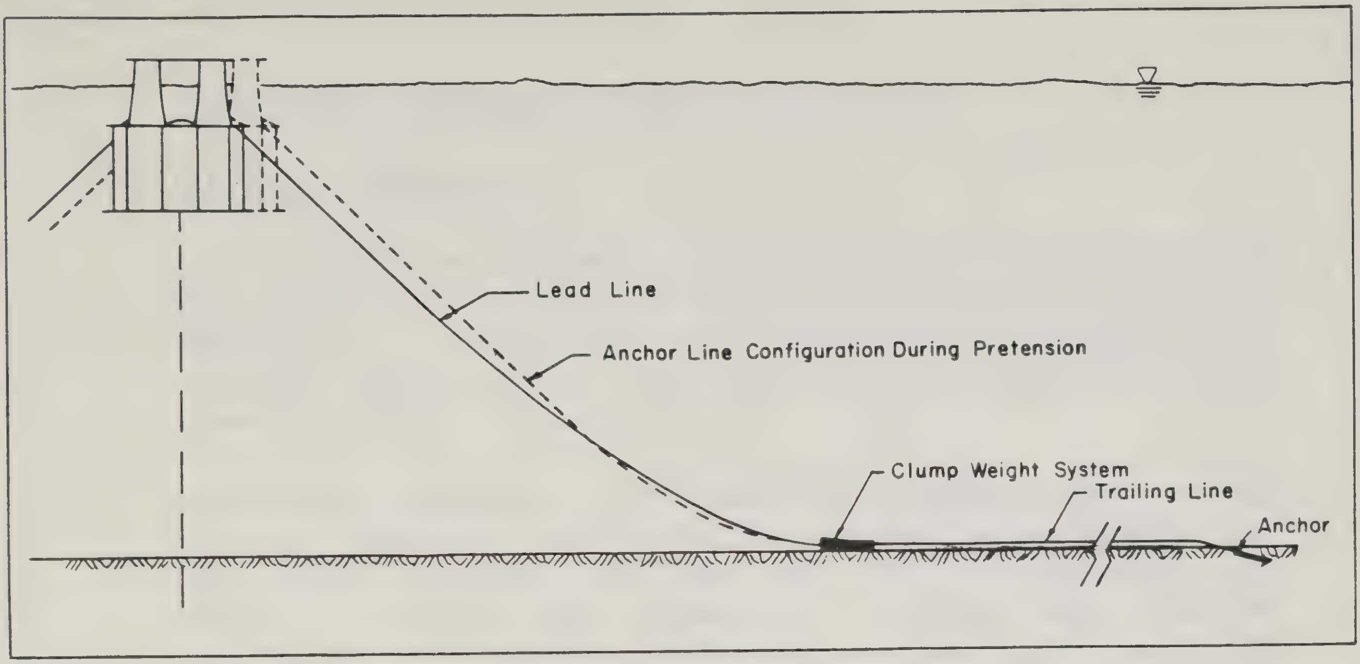
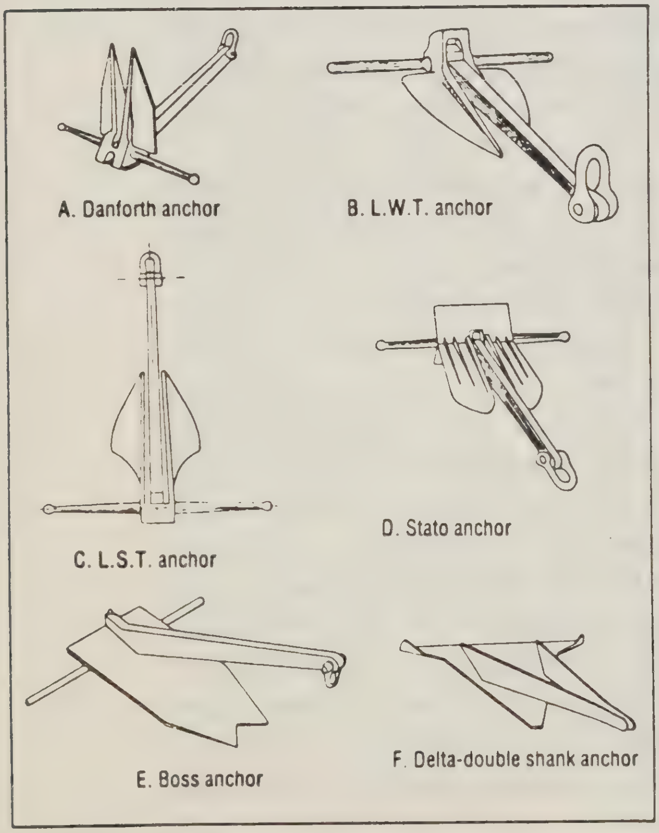


Figure 3.5: Catenary Anchoring System



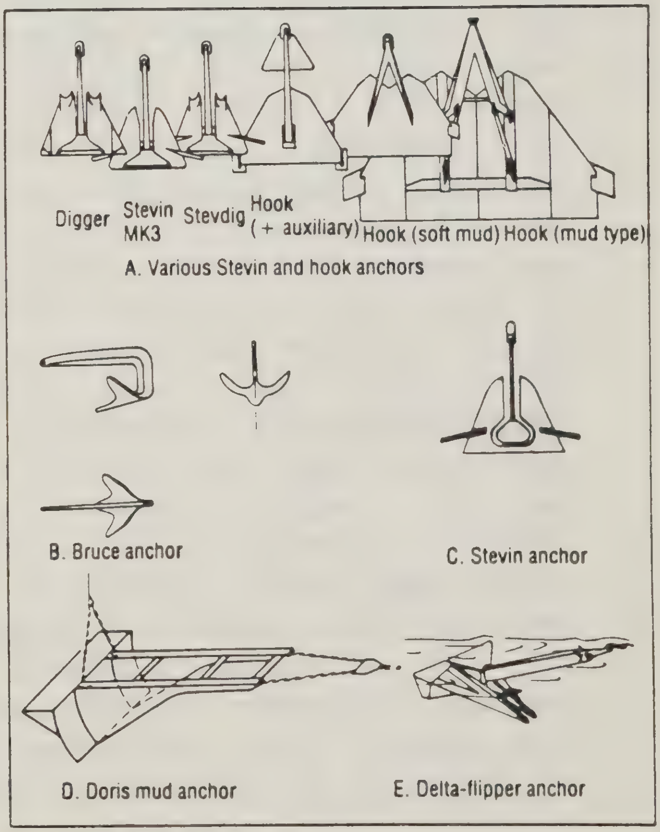


Fig. 3.6: Anchor development-ship anchors to rig anchors

Fig. 3.7: Modern rig anchors

4. ADEQUACY OF AVAILABLE SEABED INFORMATION

4.1 Types of Information

To evaluate the adequacy of available seabed information with regard to the safety of drilling operations, it is necessary to recognize the difference in geological studies, geophysical surveys and geotechnical site investigations.

Geological studies of continental shelves are mainly directed towards identifying the depositional history of the shelf deposits and the type and distribution of materials forming those deposits. Although these studies are useful for general guidance and may give valuable insight into the probability of encountering particular conditions, they do not provide the data necessary for quantifying the risk associated with drilling operations.

Geophysical surveys carried out with side scan sonar and acoustic profiling systems are an essential part of the investigation of potential drilling sites. Side scan sonar provides a detailed graphic record of seafloor irregularities such as rock outcrops, boulders and depressions; debris, pipelines and topographic features such as sand waves, mud flows and fault scarps can also be detected. High-resolution acoustic profiling systems are useful in identifying subbottom geologic features such as near surface gas which may constitute hazards during drilling; they also provide a basis for extrapolating geotechnical data and aid in identifying three-dimensional sedimentary features over a larger area than might be practically achieved by geotechnical borings. It is, however, essential to recognize that geophysical surveys use remote-sensing methods to provide data from which information on seabed materials is inferred. Because the geophysical response of geologic materials is not necessarily unique, different geologic conditions can have similar geophysical characteristics and, conversely, different geophysical characteristics can be produced by

similar geologic conditions. Geophysical data are therefore not diagnostic by themselves.

Geotechnical investigations involve the sampling and testing of the seabed materials at a proposed site; physical properties can thus be measured directly and do not have to be inferred from indirect methods. Shallow soil samples for near-seafloor investigations are obtained by gravity corers, grab samples and similar techniques. Subbottom soil samples, which are required for analysis of the behavior of drilling equipment components, are obtained by geotechnical borings. These borings provide detailed information on stratigraphy, and engineering properties are determined from laboratory tests performed on the samples recovered. In situ testing of the soils can also be carried out and this can provide information on those soil properties which cannot be determined reliably from samples because of unavoidable disturbance. In situ testing is used more frequently in investigations for permanent structures than in those performed for exploration drilling operations.

A brief description of available geophysical and geotechnical methods for the investigation of seabed conditions is given in Appendix 2. The techniques and applicabilty of both sampling and in situ measurements are outlined.

Geophysical data and data from geotechnical borings are most useful when combined in an integrated study. When geotechnical conditions can be correlated with acoustic profiles through the boring site, the geophysical data can be used to extrapolate material properties for a considerable distance. The geophysical data provide the extent and approximate thickness of soil layers and the testing of samples from the boring provides the physical properties of the materials. Both geophysical and geotechnical programs are most effectively developed if planned with an understanding of the regional geology and are most valuable if the results are tied into the regional geologic framework.

4.2 Available Information

The information available on eastern Canada seabed conditions is presented in Section 2. As discussed previously, essentially all of this information is based on geophysical survey work and geological interpretation. Very limited geotechnical data was collected during this work and it consisted primarily of near-seafloor or shallow soil sampling. Geotechnical engineering properties of the type required for analysis of seabed-structure interaction are not available.

Geological features, as noted in Section 2 and described in Appendix 1, which could be hazardous to drilling have been identified within the eastern Canada offshore but information on their distribution is not sufficient to determine which, if any, exist at a particular site.

In summary, the available information on the eastern Canada offshore seabed is considered to be qualitatively useful as a guide to probable conditions but is not sufficient to permit evaluation of their potential effects on the safety of drilling operations.

4.3 Present Practice in Eastern Canada Offshore Drilling Operations

Eastern Canada offshore drilling operations are regulated by statutes of the governments of Canada and Newfoundland and Labrador. The pertinent regulations are "The Canada Oil and Gas Drilling Regulations" and "The Newfoundland and Labrador Petroleum Drilling Regulations, 1982". Both of these Regulations deal with the various aspects of exploration for oil and gas and the measures necessary to ensure the safety of such operations. In addition, the Newfoundland and Labrador "Offshore Installations (Design, Construction and Survey) Regulations, 1982" specifies the procedures whereby fixed and mobile offshore installations are certified as being fit for their purpose.

In many instances, the practices adopted by the offshore industry may exceed the requirements of the statutory regulations. For example, both the Canada and the Newfoundland and Labrador Regulations accept anchor tests based on applying line tension equal to the capacity of the winch which could be significantly less than the maximum anticipated tension; it is understood that present practice is to test to the maximum anticipated tension. With regard to how operations relate to safety, it is, however, necessary to assume that the regulations may often determine the standard of operation. For reference purposes, the portions of the Regulations relating to the seabed and components which interact with it are presented in Appendix 3.

4.4 Information Required

To permit evaluation of the influence of seabed conditions on the safety of drilling operations, information on both geologic features and geotechnical properties is required.

The presence of potentially hazardous geologic features is best determined on a site specific basis. Because of the large area involved in the eastern Canada offshore, it would not be feasible to map all potentially hazardous features on the level of detail necessary for engineering analyses and design. Available geophysical methods can be used to identify the most critical of the previously-noted concerns. Present statutory regulations require that surveys of this nature be carried out and submitted for review before drilling at a proposed location.

The nature and geotechnical properties of the soils at the seafloor and their variation with depth must be known to analyze the equipment-seabed interaction discussed in Section 3. The specific information required depends upon the equipment component being considered; maximum detail is required for jack-up rig foundation analysis which involve classical analytical procedures while general

information is usually sufficient for conventional anchors where analysis is by empirical methods. To obtain the geotechnical information necessary for engineering analyses of equipment-seabed interaction, site specific investigations by borings, sampling, in situ testing and laboratory testing are necessary. The required scope of investigation depends on the variability of the seabed soils and the analytical methods to be used. Guidance in this regard is given in the Canadian Manual on Foundation Engineering (1978) and by the Newfoundland and Labrador Petroleum Directorate (1982).

The number and depth of borings required at a site depends upon the soil variation, the nature of the proposed structure and the amount of reliable information already obtained from other investigations such as geophysical surveys made on or near the site. For jack-up rig foundation investigations, a single boring, advanced to two footing widths in excess of the deepest expected footing penetration, is usually deemed sufficient in areas of uniform soil conditions. A sufficient number of samples is required from each boring to establish an accurate profile of the soils encountered. In borings for jack-up rig foundations, a sampling interval of about 1 metre is commonly used. A variety of sampling devices are available, each of which causes some degree of sample disturbance; selection of the appropriate sampling device must therefore consider the objective of the investigation and the acceptable degree of sample disturbance. Similarly the results of all types of in situ tests require careful interpretation; results obtained are influenced by the testing apparatus and the soil type.

After soil samples have been obtained, the geotechnical parameters required for analyses can be quantified based on the results of in situ testing, and visual examination and laboratory testing of the samples. The laboratory tests required are classification tests, including grain size distribution, water content and plasticity; and strength and deformation tests such as unconfined and

triaxial compression, direct shear, and consolidation. Special tests, such as those to measure response under cyclic loading, can also be performed depending on the project requirements.

Since all stages of a geotechnical investigation require decisions on what procedures are acceptable to meet specific objectives, their performance requires specially trained personnel.

Section 89 of the Canada Oil and Gas Drilling Regulations requires that information on the subsurface conditions and the suitabilty of the drilling program at a proposed drill site be submitted but does not specifically require that geotechnical properties of the seabed material be determined. It therefore appears that subsurface information inferred from geophysical surveys would satisfy these regulations; as discusssed above, however, this type of information is not sufficient to quantify safety risks, particularly the important problem of punch through.

Section 33 of the Newfoundland and Labrador Petroleum Drilling Regulations, 1982, requires determination of "the composition and geotechnical qualities of the seabed for the first 50 metres of sediment below the seafloor", but as these regulations are fairly new it is not clear whether this requirement is being interpreted to mean direct geotechnical investigation or indirect estimation from geophysical data. Only in the former case would the resulting information be adequate for quantifying risk. In any event, these Regulations are only applicable to a portion of the eastern Canada offshore.

CONCLUSIONS

The safety of exploratory drilling operations in the eastern Canada offshore is significantly dependent upon seabed conditions. In terms of safety, jack-up rigs represent a greater potential risk than other elements which interact with the seabed, such as anchors and well conductors.

In order to minimize the safety risks associated with exploratory drilling operations, detailed knowledge of the seabed is required. This knowledge includes the identification and engineering assessment of geological features which may occur at the site as well as identification and evaluation of the geotechnical parameters (soil strength, density, etc.) pertinent to the site and application in question.

The present knowledge of the seabed conditions on the eastern Canada offshore is not sufficient to effectively predict the performance of structural elements which interact with the seabed. The data available consist primarily of geophysical records which, with the coverage to date, have permitted only the development of regional mapping. Such mapping does not provide site specific information regarding the presence or absence of potentially hazardous seabed features. As it is not feasible to increase the coverage to a level where potential hazards at all future sites are identified, geophysical surveys are necessary on a site specific basis. Site specific geophysical surveys will be most meaningful if tied into the current regional geologic framework.

Information on the geotechnical parameters of the seabed sediments which is required for performance prediction and analysis of seabed-structure interaction is almost entirely lacking and is therefore totally inadequate. Even with a comprehensive geophysical data base, the geotechnical parameters would remain unquantified. As obtaining geotechnical information on a regional basis in the detail required for analyses at a particular site is even less practical than obtaining comparable geophysical information, site specific

geotechnical investigations are necessary. These investigations will be most useful if conducted in conjunction with site specific geophysical surveys and related to the current regional geologic framework.

Present geophysical and geotechnical equipment and techniques are sufficiently advanced to obtain the type and quality of data required for evaluation of seabed-structure interaction. Similarly, proven methods exist to predict the performance of structures on the seabed after adequate data has been obtained. Conventionally, the factors of safety used for offshore structures are smaller than used for structures on land. Increased factors of safety would be required to provide margins of safety which are comparable to those provided on land.

Existing statutory regulations applicable to the overall eastern Canada offshore do not specifically require geotechnical investigations at proposed drill sites. They thus do not ensure that the information required to quantify the risk related to seabed-structure interaction is obtained. Requiring site specific geotechnical investigations would provide the data necessary to minimize the risks involved with offshore exploration activities.

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APPENDIX 1

A1. GEOLOGIC FEATURES AND CONDITIONS

Potentially significant geologic features and conditions which have been identified on the eastern Canada offshore are discussed briefly below.

A1.1 Near-Surface Gas

Near-surface gas may comprise either biogenic gas (methane) generated in the near-surface sediments or petroleum gas that has migrated upward from depth. Near-surface gas may occur in localized zones, such as near and along faults and along the crest of structural highs, or may underlie areas of as much as several hundred square kilometers. Gas may be dispersed throughout the sediments or may be confined to specific zones such as sandy units. Gas trapped in near-surface structural closures is of particular significance due to the potential of abnormally high gas pressures and their effects on shallow drilling operations.

Occurrences of shallow biogenic gas are common in estuaries and along buried channels (King, 1979). Shallow biogenic gas generally is not under abnormally high pressure and consequently is not likely to impair exploratory drilling operations. However, dispersed biogenic gas may reduce the shear strength of sediments (Whelan, et al., 1977). Thus, near-surface gas zones may be a significant engineering constraint in some instances. Shallow accumulations of petroleum gas often are highly pressured and thus are of particular interest at proposed drilling sites.

A1.2 Pockmarks

Pockmarks are small, cone-shaped depressions on the seafloor that are present in large numbers on parts of the Scotian Shelf. The diameter of the pockmarks normally ranges from 15 to 45 m and the depth ranges from 5 to 10 m. The pockmarks were described by King and Maclean (1970), Josenhans, King, and Fader (1978), and King (1979) from echograms, side-scan sonar records, and direct observations from a submersible.

The origin and age of the pockmarks is not known with any certainty but the pockmarks are possibly erosional features formed by fluid (gas or water) expulsion. No active expulsion of gas has been noted within any of the pockmarks. Therefore, it is possible that the pockmarks are no longer forming or form by intermittent emissions of fluid. Pockmarks may be a hazard if they form rapidly. The rapid formation of a pockmark would involve total collapse and removal of the sediments within the crater.

Any potential hazard related to pockmarks cannot be fully evaluated until the mechanism of formation is understood. Therefore, pockmark areas will require investigation prior to any seafloor development in areas where they occur.

A1.3 Sediment Transport and Seafloor Scour

Conditions giving rise to sediment transport or seafloor scour may be evidenced by sand waves, megaripples, or megaflute marks.

The distribution of sand waves and megaripples on the eastern Canadian shelf is not completely known because of the lack of extensive side scan sonar coverage. These bed forms are indicators of strong currents and migrate across the seabed in response to this agent. Sand waves may sometimes be relict in which case they do not necessarily constitute an engineering hazard, but it is difficult to make a distinction between relict and modern bed forms. Those associated with the Pleistocene-Holocene shoreline are thought to be relict. (King, 1979)

Megaflute marks are tongue- to triangular-shaped depressions on the surface of sediment. The depressions are deepest at the apex end and flare out and shoal at the opposite end where they gradually merge with the sediment surface. These scour marks have been recognized on the seabed of Placentia Bay south of Newfoundland. They occur as isolated features or in groups where the individual features coalesce and overlap. These features are 100 to 200 m long and flare to widths of 50 to 150 m. Seismic sections indicate depths up to 5m. (King, 1979). The

scouring process may be active at the present time and should be of potential interest to engineers, but the rate of scouring is as yet unknown.

A1.4 Very Hard Seafloor and Boulder Beds

Hard seafloor and boulder deposits may pose anchoring problems, difficulty in spudding in and difficulty in emplacing the legs of jack-up drilling rigs and may be potential hazards to exploratory drilling. In some cases hard but thin material that first provides a firm foundation may later fail under one leg of a jack-up drilling rig after drilling has started (punch through).

Glacial moraine complexes have been described on the Scotian Shelf, south of the Burin Peninsula, east of Newfoundland and on the Labrador shelf. (King, 1979, Grant, 1972; van der Linden et al., 1976). Of importance to exploration activities is the fact that moraine deposits generally contain an abundance of gravel, cobbles and boulders which can inhibit operations. For example, boulders encountered while spudding exploratory wells on the Labrador Shelf necessitated repositioning several holes (King, 1979). This condition could be of particular importance if a relief well were required during exploratory drilling because of the potential delay it could cause.

A1.5 Rough and Irregular Seafloor

Rough and irregular seafloor is typically associated with bedrock or other hard material exposed at the seafloor. Large areas of exposed or nearly exposed bedrock occur along the inner Scotian Shelf, and this appears to be typical for most of the eastern Canadian shelf. Irregular seafloor topography is often associated with glacial debris and contains boulders. Rough and irregular seafloor is also common in areas of slide deposits and near fault scarps. Local relief in some areas may be as much as 15 m, but is typically less than 5 m.

A1.6 Relatively Steep Slopes

Relatively steep safloor slopes are associated with submarine canyons, delta fronts, diapirs or other

structural highs, erosional remnants, and other local topographic features. Beyond the edges of the continental shelves, seafloor gradients often exceed 3 percent. The term "relatively steep slopes" can apply to a range of actual seafloor gradients depending on the particular geologic setting. For example, seafloor gradients of 1 percent are considered "steep" in the vicinity of the Mississippi Delta where failures have occured on slopes of less than 1 percent. In other areas, underlain by more competent sediments, slopes may not be considered "steep" until they are 10 percent or more.

Areas where steep slopes may occur have been identified on Figs. 2.2 to 2.6. Within the area covered by weak sediments, slopes of greater than 3 percent are indicated. Slopes greater than 6 percent are indicated for all other areas. The potential hazard associated with a steep slope has to be evaluated on a site specific basis.

A1.7 Buried Channels

Filled and buried channels are relatively common on the continental shelves throughout the world. Buried channels are particularly common on offshore parts of the east coast. Many buried channels are within 120 m of the existing sea level and were formed during late Pleistocene lowstands of the sea (about 16,000 yrs BP). Buried channels often are several hundred metres wide and range from a few metres to more than 30 m deep.

Sediments in filled channels often have different geotechnical properties from sediments in surrounding areas. Consequently, buried channels may greatly affect foundation conditions in local areas and detailed investigation is required to identify and evaluate their significance.

A1.8 Submarine Slides, Slumps, Mud Flows and Creep

Various submarine mass-movement features are among the most significant potential hazards to offshore development. These features include rotational slumps and translational slides, mudflows, and surficial creep.

Large submarine landslides can occur on the upper continental slope and also in shelf areas characterized by relatively steep slopes and high sedimentation rates. Triggering mechanisms probably include seismic shaking and storm-wave loading.

The 1929 Grand Banks earthquake event created slumps on the continental slope (Heezen and Drake, 1964) which ruptured many submarine cables.

In evaluating the potential for future instability, evidence of past instability is an important factor. The presence of numerous mass-movement features in an area indicates that geologic conditions at some time in the past have produced or contributed to slope instability. Areas where mass movement has continued through time up to the recent can generally be considered high risk areas for future mass movement. On some continental slopes, mass movement is one of the predominant geologic processes. Major changes in geologic conditions can cause areas of mass movement features to become stable. During the Pleistocene lowstands, (about 16,000 years BP) many areas of the outer continental shelf and continental slope were subject to mass movement but are now stable.

Similarly, the general absence of mass-movement features in an area typically indicates stable geologic conditions. The slopes are likely to remain stable unless overall geologic conditions change or a unusual phenomenon, such as a major earthquake, occurs.

Regional geologic studies on the continental shelf offshore eastern Canada, which have been extensive in some areas, have found little evidence of mass movements. Examples, however, of possible mass-movement features that have been described on the continental shelf offshore eastern Canada are as follows: Sediments that may have been transported downslope by mass movement were described from cores on the northeast Newfoundland Shelf (Piper, et al.,1978) and from cores in Hawke Saddle (Vilks, 1980). Slump topography northeast of Sable Island has been observed. (Amos, personal communication).

A1.9 Weak Seafloor Materials

Very soft materials can cause difficulty with anchoring, with guide base performance, and with the successful use of jack-up drilling rigs; they can therefore be categorized as a potential hazard to exploratory drilling operations. These materials also require special foundation design considerations and are commonly susceptible to partial or total strength loss from loading by waves or earthquakes.

A1.10 Structural and Tectonic Elements

This category of feature includes faults, earthquake epicentres and shallow salt domes, all of which can influence exploration activities. For example, movements on faults in bedrock underlying seabed sediments could affect seabed stability through displacement of sediments and inducement of mass movements, or through the generation of earthquakes. The Glooscap fault is the best example of faulting on the Scotian Shelf and it is believed that motion of this system was responsible for the 1929 Grand Banks earthquake. It appears that earthquake epicentres are associated with this fault system.

Shallow salt domes constitute potential sites for bedrock movement which could affect exploration activities. The Obanaki salt dome north of Sable Island is an example.

In addition to the potential for seismic shaking, deep seated faults that extend upward to shallow depths also may act as conduits along which potentially hazardous gas can migrate upward from deeper reservoirs.

Little data is currently available on the frequency and intensity of seismic events on the eastern continental shelf. (Basham, et al., 1983) Projects are being initiated, however, to monitor seismic activity on the Scotian Shelf (C.F.M. Lewis, personal communication).

A1.11 Iceberg Scour

The potential effects of ice gouging must be considered in many areas of the eastern Canada shelf. Gouging of the seafloor is caused by icebergs and by rafted sea ice, as in pressure ridges. Winds and currents force many icebergs and pressure ridges into shallow water where they become grounded. Where the seafloor sediments are relatively soft, large gouges form as the momentum of the ice is dissipated. Such gouges can present a potential hazard to jack-up rig foundations.

Both modern and relict iceberg furrows are a common occurrence along the entire eastern Canadian shelf and have been documented in papers such as Harris and Jollymore (1974), van der Linden et al., (1976), King (1976), Lewis et al., (1979), and d'Apollonia and Lewis, (1981. Severe scouring with intense sediment reworking is reported on the Baffin Island shelf (MacLean, in prep.). Furrow dimensions are highly variable but typically, they are approximately 2 m deep, 30 to 40 m wide, and can be many kilometres in length. It is difficult to distinguish between relict and modern furrows because they both can display a fresh, well preserved appearance. It is only through regional considerations concerning the distribution of ice that definite conclusions can be drawn. For example, the furrows on the Scotian Shelf must be relict because of the relative absence of icebergs since the continental ice sheet withdrew (about 10,000 years BP). Distribution studies of iceberg furrows are important from an engineering viewpoint because the relative absence of furrows may indicate the existence of areas protected from icebergs. The collective influence of morphology, sediment type, currents, prevailing winds, and average shape and size of icebergs could strongly affect the local distribution of furrows.

A1.12 Gas Hydrates

Gas hydrates are ice-like solids, formed by a combination of water and an encaged gas molecule, that can remain stable above the freezing point of water. Gas hydrates exist in both shallow and deep water in offshore sediments in some areas of the Arctic (National Research Council, 1982). Hydrates evolve into gas upon thawing and may produce significant formation pressures. The decomposition of hydrates due to decreased pressure or increased temperature around a well bore may result in loss of strength of the affected sediments and in the discharge of large volumes of gas. These sediments thus deserve consideration as potential hazards in foundation and well casing design.

A1.13 Submarine Permafrost

Submarine permafrost is present in the shallow sediments in some northern offshore areas (Hunter et al.,1978; Sellmann and Chamberlain, 1979). The vertical and lateral distribution and the characteristics of submarine permafrost are poorly known and thus its engineering significance is uncertain. Permafrost may simply consist of permanently frozen soil that is not supersaturated (i.e. all frozen water is interstitial); melting results chiefly in lower shear strength. Permafrost may contain masses of excess ice; melting typically results in ground collapse or sinking, as well as in reduced shear strength. A number of investigations to determine the characteristics of submarine permafrost have been conducted or are now in progress, including studies to determine whether high-resolution geophysical data can be used to detect submarine permafrost or if new methods of sampling and testing will be the only reliable means of detection (Hunter et al.,1978; Rogers and Morack, 1978).

A1.14 Man-made Objects

Man-made objects such as subsea production equipment, pipelines, cables, shipwrecks and assorted debris from man's activities are found on or just below the seafloor in many offshore areas. The engineering significance of such objects depends upon their nature and location as well as the type of activity planned in an area. Locating man-made objects may be a primary objective of some site studies; ferrous-metal objects on or just below the seafloor can usually be detected by marine magnetometer surveys. If such objects are unexpectedly encountered during exploration or construction, subsea facilities may be damaged, anchors may be lost, and costly delays often result.

APPENDIX 2

A2 AVAILABLE METHODS OF SEABED INVESTIGATION

A2.1 High-Resolution Geophysical Data Acquisition

High-resolution geophysical surveys are used to characterize the regional geology of a study area. High-resolution geophysical data are the basis for the present understanding of the geology of the continental shelf. High-resolution geophysical data are used to infer the seafloor topography and the thickness and extent of various sediment and rock units. The following is a brief review of the types of equipment that are employed when performing geophysical surveys. A discussion of appropriate survey grids is also presented.

A2.1.1 Survey Equipment

Several specialized geophysical systems are normally operated simultaneously along survey gridlines. These systems provide information about water depth and seafloor topography, soil reflectors to depths of at least several hundred metres below the seafloor, and geological conditions. Each of the systems (except the marine magnetometer) operates by transmitting acoustic pulses and displaying the reflections, from the seafloor or buried strata, on a continuous graphic record. Although there are many trade names for the various systems available, the three basic categories of acoustic systems used are: water depth recorders, side-scan sonars, and sub-bottom profilers. The simultaneous operation of all of these systems provides the most information for the least cost.

Water Depth Recorder

A water-depth recorder provides accurate water depths. Normally, all reflections received by water-depth recorder are from the seafloor directly beneath the survey vessel.

Reflections are displayed as a function of time and are plotted side-by-side to provide a continuous profile of the seafloor. Water depth is determined based on the velocity of sound in water.

Side-Scan Sonar

The side-scan sonar provides a plan view of the seafloor. The side-scan sonar system transmits a fan-shaped beam directed to either side of the survey vessel. All reflections are from the seafloor but, unlike the water-depth recorder, reflections are from a strip of seafloor on either side of the side-scan transducer, rather than from directly beneath it. As a result, side-scan records are similar to low-oblique aerial photographs. The width of the swath displayed on the record is variable. Some "mid-range" side-scans are capable of displaying 1 to 2 km widths; these data are particularly useful for regional studies. Traditional, short-range side-scans display swaths of 100 to 400 metres; these records are most useful to investigate smaller features and for site specific studies. Side-scan sonar records are useful for mapping areas of rock outcrop, boulders, and similar seafloor features.

Sub-Bottom Profiler

Sub-bottom profilers provide vertical acoustic response profiles of strata beneath the survey trackline. Sub-bottom profilers operate at lower frequencies than most water-depth and side-scan sonar systems; this lower frequency allows much of the

transmitted energy to penetrate the seafloor. Some of the energy is reflected from the top of each successive deeper soil or rock reflector. Each of these sets of reflections is recorded as a function of time; successive sets of reflections are plotted side-by-side to form a continuous profile.

Three separate sub-bottom profiler systems, operating at different frequencies and providing different resolution, are normally operated simultaneously. This provides detail in the shallowest sediments and also provides information to depths of several hundred metres, although at less detail. Shallow-penetration profilers portray soil and rock reflectors to maximum depths of about 30 m and maximum operational resolution is typically 0.5 to 1 m. An example of the shallow-penetration profiler is a 3.5 kHz profiling system. Intermediate-penetration profilers portray reflectors to maximum depths of 75 to 200 m, depending on specific system being used; maximum operational resolution is typically 1 to 2 m. Boomer-type systems such as the Huntec deep-tow system, Acoustipulse, and Uniboom as well as minisparkers are examples of intermediate-penetration profilers. Deep-penetration profilers portray reflectors to maximum depths of about 900 m and maximum operational resolution is about 9 m. Examples include water guns, air guns, sparkers, and minisleeve exploders. Actual penetration for all systems is largely a function of the acoustic characteristics of the soil or rock. For example, greatest penetration is achieved in soft clayey sediments, and little or none in hard rock.

Marine Magnetometer

The marine-magnetometer system detects and records the total intensity of the earth's magnetic field. This is the only geophysical system used routinely for site surveys that is not an acoustic system. The magnetometer system is designed to be particularly

sensitive to local variations in field intensity; its sensitivity to magnetic anomalies makes it useful for locating pipelines, well heads, wrecks, and other ferrous-metal objects on or just below the seafloor. This system is most useful when used with the side-scan sonar system because the identity of an object cannot be determined solely from the character of a magnetic anomaly.

A2.1.2 Survey Grids

Geophysical data are most useful when acquired over regular survey grids. Grids typically consist of two sets of parallel lines intersecting at right angles. Ideally, the survey grid should be oriented so that lines coincide with the geologic strike and dip directions. Line spacing depends on geologic and operational considerations; for regional, reconnaissance surveys of areas such as the eastern Canadian shelf, dip lines at intervals of 2 to 10 kilometers and strike lines at 5 to 15 kilometers spacing would be appropriate. For site specific studies, normally an area of about 3 kilometers on a side should be surveyed. Line spacing for site specific studies is typically 150 to 300 m by 500 to 1000 m. Line spacing closer than 150 m is rarely justifiable, except in the most complex areas.

A2.2 Geotechnical Sampling and In Situ Testing

Sampling of offshore sediments is a very important part of field investigation. The sampling methods should be those that minimize soil distrubance which can have a pronounced effect on the measured shear strength of soils.

In situ measurements of soil properties can supplement conventional sampling programs when more detailed geotechnical information is required. In situ tools have been used for many years, and the number of tools continues to increase.

A2.2.1 Sediment Sampling Equipment

A wide variety of soil sampling devices appropriate for use on the continental shelf have been developed. These devices include various gravity coring devices, vibra-cores, wire-line driven samplers, latch-in push samplers, hydraulic piston corers, pressurized core barrels, the Swordfish system, the Wipsampler, and the Stingray system. These devices obtain soil samples with varying degrees of disturbance, and are designed to operate at various maximum water depths and seabed penetrations.

A2.2.2 Geotechnical Tools for In Situ Measurements

Conventional sampling programs are sometimes inadequate as a single source of geotechnical field information for design decisions. Economics, project complexity, and the departure-from-precedent of many projects today, often combine to justify a detailed study of soil properties measured by in situ tests. Geotechnical in situ tests and the subsequent design analyses based on these tests are becoming more cost effective although their use is more common in investigations for permanent structures than in investigations conducted for exploratory drilling activities.

In the following sections, the geotechnical tools for in situ measurements are discussed.

<u>Cone Penetrometer Tests</u>

The Cone Penetrometer Test (CPT) has been used widely offshore from floating vessels since 1970. Cone penetrometer tests are performed in a variety of soil types ranging from soft clay to very dense sand. A number of different types of CPT tests have been developed, such as quasistatic CPT (QS-CPT), dynamic CPT, and the impact CPT. The QS-CPT is the most widely used and accepted method for performing cone penetrometer tests and is the only method discussed herein.

The QS-CPT consists of pushing a standard cone penetrometer into the soil at the prescribed rate of 2 cm/sec ±25 percent. The standard cone has a projected point area of 10 cm^2, and friction sleeve areas of 100, 150, or 200 cm^2.

Most cone penetrometers used offshore use calibrated electric force transducers to measure the point resistance and sleeve friction. Force transducers should have measuring capacities that are compatible to the strength of soils being tested.

Vane Shear Tests

Vane shear tests have been conducted offshore for a number of years. (Richards, 1972). Vane tests are generally performed in cohesive soils with undrained shear strengths of 2 to 150 kPa.

The basic test consists of pushing a four-sided blade into the soil. The blade is then rotated and the resulting torque is measured. This torque is used to compute the undrained shear strength. Numerous technical papers have been written on the theory and interpretation of vane shear testing (Bjerrum, 1972).

The vane test theoretically has no water depth limitation. Vane tests have been successfully completed from tethered seabottom platforms in over 3300 m of water and through-the-drill string in a combined water depth and penetration of 915 m.

Pressuremeter Tests

The pressuremeter test has been used routinely onshore and in shallow water for a number of years. Development of pressuremeters capable of operating in water depths over 30 to 60 m is relatively new.

The pressuremeter test probably yields the greatest amount of information concerning the in situ properties of soils. Some of the more important soil properties that are measured are: coefficients of earth pressure at rest, secant shear modulus for any volumetric strain, and undrained shear strength. Soil classification is also possible. The pressuremeter test has the added distinction of being the only in situ test in cohesive soil capable of yielding a stress-strain curve. The most obvious drawback of the pressuremeter is its limited use offshore to date.

Natural Gamma Logging

Borehole logging techniques have been used to a varying degree on offshore geotechnical investigations over the past few years. The most commonly used device is the natural gamma logger which is a probe that measures the amount of natural gamma radiation present in the soil surrounding the borehole.

The natural gamma log provides useful information on the location of stratigraphic changes within a borehole. In sampling programs where sample intervals may approach 6 m, precise determination of stratigraphic changes is not possible.

The accuracy of the gamma log is dependent on the accuracy of the depth measurement in the borehole. The accuracy of the depth measurement depends on the type of vessel, the sea state, and whether the drill string is compensated or uncompensated. If compensation is provided, gamma logging can be performed from most vessels in sea states that do not curtail the drill operation. If the drill string and logging cable are uncompensated, the vessel period and sea state may limit the use of the logger.

APPENDIX 3

A3. STATUTORY REGULATIONS RELATING TO OFFSHORE DRILLING

The portions of the Regulations relating to the seabed and the drilling equipment components which interact with it are presented below.

A3.1 General Seabed Information

A3.1.1 The Canada Oil and Gas Drilling Regulations.

These regulations state the following with regard to seabed conditions.

Section 8: "The following information shall be furnished and forwarded with the application for approval of a drilling program: .....

(f) where the program is to be carried out offshore,
(i) particulars of the nature of the seafloor in the proposed drill site,"

Section 21: "Every operator shall take all reasonable precautions for the protection of personnel and equipment from naturally-occurring and man-made hazards in the area described in the Drilling Program Approval issued to that operator."

Section 89: "(1) Every operator shall prepare a well prognosis to supplement information submitted in accordance with section 8...

3(b) part two of the prognosis shall provide information in respect of surface conditions in the vicinity of the well that may affect the safety and efficiency of operations and where the well is offshore, the anticipated meteorological and oceanographic conditions and the topography and composition of the seafloor:

3(c) part three of the prognosis shall provide information in respect of the subsurface conditions anticipated at the proposed drill site that may affect the safety and efficiency of the drilling operations and shall include

(i) the depth and thickness of geological formations and the depth of geological markers,

(ii) the depth and nature of formations where problems such as lost circulation zones, swelling shale zones and permafrost zones are anticipated,

(iii) where the proposed well is offshore, the anticipated depth of unconsolidated sand and gravel below the seafloor;"

A3.1.2 The Newfoundland and Labrador Petroleum Drilling Regulations, 1982.

With regard to seabed conditions, these regulations have very similar requirements to those listed above from the Canada Oil and Gas Drilling Regulations. However, more specific wellsite survey information is required as follows:

Section 33: "Where the proposed well is offshore, every operator shall prepare a wellsite survey to

(a) map the detailed bathymetry of the wellsite area;

(b) determine the nature of the seafloor topography and of the water - sediment interface;

(c) determine the composition and geotechnical qualities of the seabed for the first 50 metres of sediment below the seafloor; and

(d) identify shallow geological hazards in the seabed over the first 600 metres of sediments."

A3.1.3 The Offshore Installations (Design, Construction and Survey) Regulations, 1982

These regulations state the following with regard to seabed conditions:

<u>Part I, Sections 1 and 2</u>:

"1. Every offshore installation shall be capable of withstanding the effects of any combination of -

(a) meteorological and oceanological conditions; and

(b) for fixed offshore installation, properties and configuration of the seabed and subsoil;

to which it may foreseeably be subjected at the place at which it is, or is intended to be, located, as assessed in accordance with paragraphs 2 and 3.

2. An assessment of the matters referred to in paragraph (1) (to such extent as may be relevant to the offshore installation concerned) shall take into consideration-

...

(f) characteristics of the seabed which may affect the foundations of the offshore installation;

A3.2 Foundations

A3.2.1 The Canada Oil and Gas Drilling Regulations

These regulations require the following with regard to drilling units supported by the seabed.

<u>Section 145</u>: "(1) Where an operator uses a drilling unit in a drilling program that is not a floating drilling unit, he shall ensure that

(a) the mat, legs, footings, hull or piles of the unit and the surrounding seafloor are inspected regularly, where practicable, to confirm that no areas of weakness are developing; and

(b) where scour, buildup of seafloor sediments or any other condition that threatens the stability of the drilling unit occurs, such measures as are necessary to protect the safety of the drilling unit and of the personnel on board are taken."

A3.2.2 The Newfoundland and Labrador Petroleum Drilling Regulations, 1982.

These regulations are identical to the Canada Oil and Gas Regulations on this subject.

A3.2.3 The Offshore Installations (Design, Construction and Survey) Regulations, 1982.

These regulations require the following with regard to drilling units supported by the seabed:

Part II, Sections 1 and 2:

"1. Those parts of an offshore installation which either from time to time or at all times are, or are intended to be, in direct contact with, and transmitting loads to, the sea bed and subsoil shall be capable of maintaining the integrity of the primary structure of the offshore installation and of the sea bed and subsoil and generally of supporting the offshore installation and maintaining it in a safe and stable condition.

2. An assessment of the matters referred to in paragraph 1 shall include an investigation of the site or intended site of the offshore installation concerned in order to ascertain and take into consideration-

(a) the configuration of the sea bed and subsoil;

(b) the properties and conditions of the sea bed and subsoil;

(c) the presence of any man-made hazards or obstructions; and

(d) all other factors likely to affect the stability of the sea bed and subsoil including faults, ice ridges, icebergs, seismicity, etc.

at that site, such investigation to comply, so far as possible under marine conditions, with a recognized code of practice."

Part III, Section 3(b):

"3 (b). Every offshore installation designed to be supported from time to time by the sea bed and subsoil shall-

(i) be capable of withstanding the sliding forces and the overturning moments to which it may foreseeably be subjected; and

(ii) impose on the foundation only such loads as may safely be supported by the sea bed and subsoil, and without causing settlement likely to endanger the integrity and stability of the offshore installation."

A3.3 Anchors

A3.3.1 The Canadian Oil and Gas Drilling Regulations.

These regulations state the following relating to anchors:

Section 8(h)(ii): "The following information shall be furnished and forwarded with the application for approval of a drilling program...where the program is to be carried out offshore, the details on which the applicant relies to show that...where anchors are to be used to hold the drilling unit on the well location, the method and equipment to be used to hold the drilling unit is capable of maintaining the unit within the anchor pattern under conditions of the statistical fifty-year-storm calculated to occur during the period of the year that the program is to be conducted."

Section 130(4): "Every operator shall ensure that any drilling program in progress at a drill site that is offshore is suspended where any of the following conditions exist:...

(l) where a drilling unit is anchored, the tension on any anchor exceeds the values established when the anchor was set."

Section 144: "(1) Where anchors are used for holding any drilling unit used in a drilling program in position at a well site, each anchor line and anchor shall be tested, prior to the commencement of drilling operations, to a tension equal to the lesser of

(a) the maximum anticipated tension expected during the time the drilling unit is on the well site; and

(b) the capacity of the winch.

(2) Where a tension load equal to the lesser of subsections (1)(a) and (b) cannot be applied to the anchor line, the operator shall take such remedial action as is necessary to ensure that the drilling unit is securely anchored."

Section 177: "Where any drilling program is offshore and the drilling unit is a floating unit, the operator shall

(a) observe and record at least once every six hours, when the wind speed does not exceed 35 km/h, and at least once every three hours, when the wind speed exceeds 35 km/h, ...

(ii) the tension on every anchor line;"

A3.3.3 The Newfoundland and Labrador Petroleum Drilling Regulations, 1982.

These regulations are identical to the Canada Oil and Gas Drilling Regulations with regard to anchors.

A3.3.3 The Offshore Installations (Design, Construction and Survey) Regulations, 1982.

These regulations cover mooring systems mainly with regard to their mechanical characteristics but the following is stated:

Part VII, Section 5(a): "Where an offshore installation is equipped with a mooring system such system shall be capable of enabling the offshore installation to be securely moored in all conditions permitting operations to be carried on. Such systems may be considered in association with dynamic positioning systems."

A3.4 Well Conductors

A3.4.1 The Canada Oil and Gas Drilling Regulations.

With regard to interaction between conductors and seabed materials, these regulations require the following:

Section 63: "(1) Every operator shall submit to the Chief for approval the casing setting depths, the casing program and the casing cementing program for each test hole or well that he intends to drill....
(4) where a floating drilling unit is used to drill a well, the conductor casing for that well shall be designed to have sufficient structural strength to support the load imposed by the marine riser and by the diverter or blowout preventers.
(5) When designing the conductor casing referred to in subsection (4) the support provided by the conductor pipe may be taken into account."

Section 70: "(3) Where normal pressure conditions exist, the casing program shall, in respect of any exploratory well that is offshore, include

(a) conductor pipe set at a minimum depth of 10 m below the seafloor;

(b) one or more conductor casings set at a depth not exceeding 250 m below the seafloor unless a diverter system is installed on a cemented conductor pipe or previous conductor casing in which case the conductor casing shall be set at a depth not deeper than the greater of

(i) four times the depth of the previous conductor casing or cemented conductor pipe, and

(ii) 500 m;"

A3.4.2 The Newfoundland and Labrador Petroleum Drilling Regulations, 1982.

These regulations are identical to the Canada Oil and Gas Drilling Regulations with regard to conductor and seabed materials interaction.

A3.4.3 The Offshore Installations (Design, Construction and Survey) Regulations, 1982.

Not applicable.

GLOSSARY

ACOUSTICALLY TRANSPARENT - having no acoustic reflectors and therefore appearing as a blank on acoustic records.

BATHYMETRY - the measurement of the depths of oceans, seas, or other large bodies of water.

CRETACEOUS - see "geologic time".

DESICCATE - to remove moisture; dehydrate;

DIAPIR - an intrusion which domes the overlying cover after piercing the lower layers.

DRIFT - all glacial deposits left after the retreat of glaciers and ice sheets.

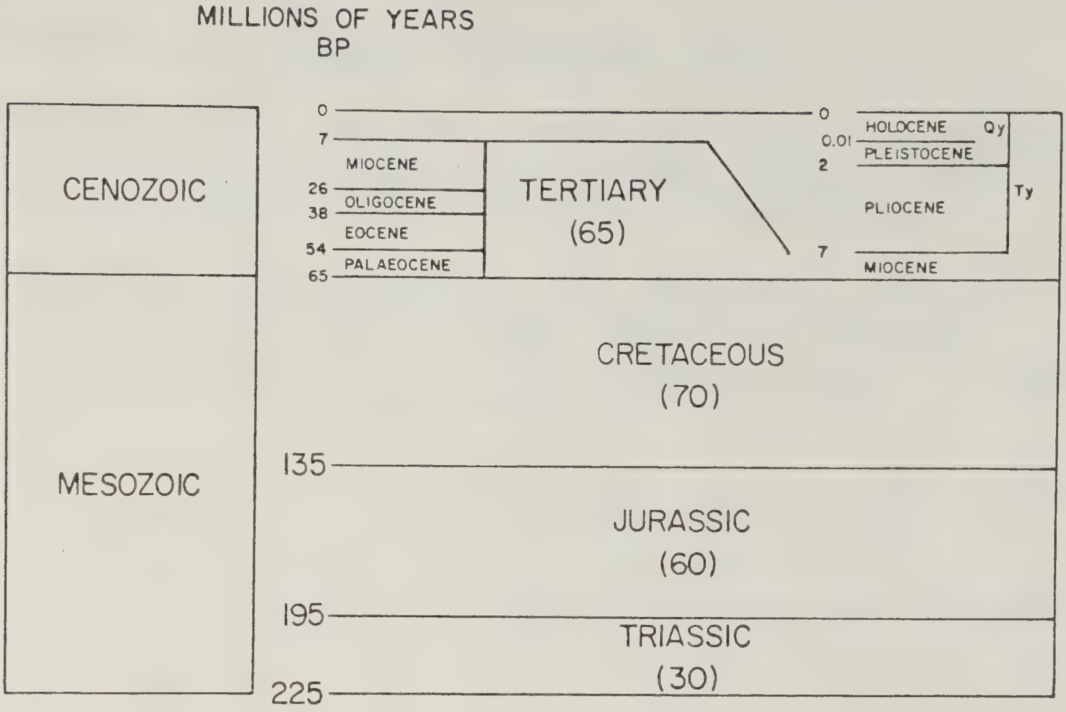
EPICENTRE - the point on the surface of the earth above the focus of an earthquake.

ESTUARY - the part of the mouth or lower course of a river in which the river's current meets the sea's tide.

FAULT - a fracture in rock along which there has been an observable amount of movement.

FINE GRAINED - in soils, refers to grain sizes smaller than 74 microns (Unified Soil Classification)

GEOLOGIC TIME -



Qy = Quarternary
Ty = Tertiary
Wisconsinan = portion of Pleistocene (10,000 - 75,000 BP)
( ) = duration in millions of years

GEOPHYSICAL - refers to the phenomena which have a bearing on the structure, physical conditions and evolutionary history of the earth. Included in geophysical surveys may be seismic (acoustic) surveys, magnetometer surveys, and gravitometric surveys.

GEOTECHNICAL - refers to engineering principles applied to soil and rock.

HOLOCENE - see "geologic time".

KAME - steep sided cone deposited against an ice front.

KETTLE - depression left in the land surface when ice, formerly covered by drift, melts.

LOWSTAND - low elevation of mean sea level.

MEGAFLUTE MARKS - megaflute marks are tongue - to triangular - shaped erosional depressions on the seafloor. They are 100 to 200 m long and flare to widths of 50 to 150 m.

MEGARIPPLES - sharp-crested, flow transverse, discrete bedform composed of medium to coarse sand and exhibiting a simple ripple - like profile. They generally range in height from 0.1 - 2.0 m and in wavelength from 0.2 - 50 m.

MORAINE - an accumulation of material which has been transported or deposited by ice. Material carried by the ice is deposited when the ice melts; such deposition occurs during a period when the ice is neither advancing nor retreating and results in a terminal or end moraine. Recessional moraines are formed as the ice retreats, each moraine representing a temporary halt in the retreat.

MORPHOLOGY - form or structure.

OUTWASH - the material, chiefly sand and gravel, washed from a glacier by the action of meltwater.

PLEISTOCENE - see "geologic time".

PROGLACIAL - environment directly adjacent to the leading edge of a glacier.

QUARTERNARY - see "geologic time"

SADDLE - a ridge connecting two higher elevations.

SAND WAVE - a composite, flow transverse, constructive bedform, formed in medium to coarse sand, constructed and transported by the superposition and migration of megaripples. Sand waves range in height from 0.5 - 12 m and wave length from 12 - 1000 m.

SCARP - a line of cliffs or vertical faces formed by faulting or mass movements.

SCOUR - the erosive force of moving water; to dig out as by the force of water.

SEDIMENT - mineral or organic matter deposited by air, water or ice. In a geological context, sediment may be consolidated (rock), or unconsolidated (soil).

SEISMIC FACIES - the composite nature of sedimentary deposits as characterized by seismic/acoustic methods.

SEISMIC PROFILE - stratigraphic section as determined using seismic/acoustic methods.

SUBAQUEOUS - existing or situated under water

SUBLITTORAL - refering to the environment immediately below the lowest level of spring tides.

TERRACE - a nearly level strip of land with a more or less abrupt descent along the margin of the sea.

TILL - unstratified unsorted glacial drift laid down either beneath the ice or dropped from the surface as the ice melted.

TOPOGRAPHY - the relief features or surface configuration of an area.

TRANSGRESS - with respect to the oceans, to encroach upon land areas due to a rise in sea level.

TROUGH - a long depression or hollow.

WISCONSINAN - see "geologic time".

WINNOW - to drive or blow smaller or lighter particles with a stream of air or water.